United Nations University
Institute on Comparative Regional Integration Studies

WORKINGPAPER

No. 03, 2024

Irrigation as an Adaptation Strategy for Climate Change: A Comparative Case Study of India and Tajikistan

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Abstract

In this paper, we conduct a comprehensive analysis of the role played by irrigation in protecting the incomes and livelihoods of agricultural workers in the face of climate change. To this end, we employ subnational irrigation statistics, which rarely appear in the academic literature due to data availability constraints and analyse them against a range of socio-economic and environmental indicators. To limit the variation in circumstances and context, we focus on two specific cases: India and Tajikistan, both among the world's most irrigated countries, with approximately 70% of the total cultivated area equipped for irrigation. We conduct a comprehensive comparative case study of the two countries' water and irrigation sectors concerning their socioeconomic contexts, climate conditions, andland and water resources. Irrigation development and relevant management frameworks are evaluated at different levels of governance – national, regional, and local – while taking into account geographic variation. Our analysis deploys longitudinal subnational statistics and demonstrates significant regional heterogeneity in irrigation deployment, which may be attributed to regions' varying water requirements, as well as financial and institutional capabilities to manage irrigation effectively.

So far, in the growing body of literature on irrigation as a solution for climate change-related shocks, it has not been fully explored how the efficient management of irrigation within countries can help tackle both economic and environmental issues at once, while considering all kinds of limitations they may face. The contribution of this article is to bridge the gap between scarce subnational statistics and scattered evidence from academic literature and reports by international and local development agencies to develop a holistic strategy for the irrigation sector in India and Tajikistan. Our findings aim to inform the scientific management of water resources, and irrigation by policymakers in India, Tajikistan, and other countries and regions worldwide that face similar issues of food insecurity, rural poverty, environmental degradation, and climate-induced migration.

Specifically, we put forward an extensive set of policy recommendations that can be beneficial for water and irrigation sectors in India and Tajikistan, with the goal of ensuring physical safety, food security, and decent economic and ecological conditions for the population. The main direction we propose is to reconcile water supply and demand across countries' regions through management reforms, infrastructural development, and improved water use efficiency and cropping patterns.

Our recommendations cover a wide range of areas for potential improvement, including the quality of infrastructure used for irrigation, drainage, and water storage, the extent of water conservation and use efficiency, provision of training and agricultural extension services, involvement of stakeholders at various levels in all stages of water and irrigation management, climate-smart optimization of cropping plans, and disaster preparedness.

Keywords

Irrigation, Food insecurity, Climate change, India, Tajikistan, Migration

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1. Introduction

Food security and rural poverty have been among the most pressing issues in development economics for many decades. With the world's population estimated to rise by 2 billion, reaching 9.8 billion by 2050 (primarily in Asia and Africa) – existing food production systems are facing enormous challenges (Saeed, 2020; IFPRI, 2017). To meet the ballooning nutritional needs, the production of food must be increased by 50% at the global level and doubled in the Global South compared to 2013 (FAO, 2017). Considering the shrinking availability of agricultural land, irrigation is expected to play a major role in increasing agricultural productivity and addressing food demand since irrigated agriculture is, on average, twice as productive per unit of cropland as rainfed agriculture (World Bank, 2020a).

Existing food supply uncertainties in the Global South are further exacerbated by the global food crisis provoked by the war in Ukraine and the blockade of the Black Sea ports. Disruption of grain and fertilizer exports from Ukraine, which is the world's breadbasket, and sanctions imposed on agricultural and oil exports from Russia caused acute food shortages and a sharp increase in prices (Espiner, 2022). With other major food exporters like China and Indonesia limiting their exports to protect domestic food security, low- and middle-income countries (LMICs) that are heavily reliant on food imports were put in a dire situation (Faulder, 2022). Inflation of cooking oils, grains, and fertilizers was most acute in Africa, South Asia, and Central Asia (ADB, 2022). The crisis has further emphasized the need for strengthening national capacities for food production, in order to increase countries' resilience to external disruptions in food supply and protect local populations.

On top of that, food and income security in the Global South are threatened by climate change, causing shifts in temperature and precipitation patterns and hence inducing, among others, water shortages and droughts in some areas and floods in others (Hen-I Lin et al., 2022; Aryal et al., 2020). These changes disproportionally penalize the most vulnerable populations that depend on agriculture to sustain their livelihoods.

In response to these slow- and fast-onset climate events, environmental migration is becoming a widespread phenomenon in the Global South, and in Asia in particular. People predominantly migrate from areas with low water availability and agricultural productivity, as well as areas that are prone to extreme climate events. The latest Groundswell report by the World Bank estimates that, by 2050, the number of internal climate migrants could reach 40.5 million in South Asia and 5.1 million in Eastern Europe and Central Asia (1.8% and 2.3 % of the total population, respectively (Clement et al., 2021).

Climate change also causes international migration, although to a much lesser extent (Cundill et al., 2021). It was estimated that each year between 2008 and 2016, on average, 21.5 million people were forcedly displaced due to sudden onset weather-related hazards, and the figures that consider migration due to long-term climate hazards are even higher (UNHCR, 2016). Once again, Asia appears among the most vulnerable regions where international migration plays the role of a climate change adaptation strategy (Maharjan et al., 2020).

Yet, not everybody moves in the face of climate change. Large numbers of people affected are considered "trapped populations", who are highly exposed to climate-related threats but cannot resort to migration due to deep and persistent poverty that makes the financial costs of migrating unbearable (Nawrotzki & DeWaard, 2018; The White House, 2021; DeWaard et al., 2022). Moreover, many choose not to leave despite increasingly dreadful circumstances, i.e., the so-called "voluntary immobile" (Ayeb-Karlsson et al., 2020; Adams, 2016; Mallick & Schanze, 2020).

The solution to the looming food crisis must be found amidst the worsening climate situation, which is largely affecting agricultural production and the availability of water resources. Again, irrigation is a crucial component here. On the one hand, irrigation is considered a robust climate-smart agricultural technology (IFPRI, 2015). Creating sustainable irrigation in hitherto underperforming rainfed croplands allows for higher agricultural water productivity, especially in heat- and water-stressed areas (Rosa, 2022; Taylor, 2022). Moreover, irrigation has a heat mitigation capacity, as it decreases regional temperatures during crop growing seasons by up to 4 degrees Celsius (Benonnier et al., 2019; Rao and Anitha, 2020; Wang et al., 2019).

However, on the negative side, irrigation remains the largest consumer of water, accounting for 70% of global freshwater withdrawals (Dankova, 2019). Given the growing non-agricultural demands for freshwater and biofuel, irrigation often fails to justify the immense rates of water and energy consumption, especially when its poor management results in low efficiency (Zukaro & Ruberto, 2019). Moreover, improperly managed irrigation leads to soil degradation, salinization, and water pollution (Bilgili et al, 2018; Wang et al., 2019; Taylor, 2022). Intense irrigation is also associated with increased moist heat stress (Mishra et al., 2020a). Hence, to contribute to solving the food and climate crises instead of exacerbating them, irrigation development must be supported by extensive research in agricultural water management.

When seeking optimal, sustainable irrigation strategies that maximize benefits for agricultural production while minimizing costs – both financial, as irrigation systems are extremely expensive to build and maintain, and environmental – it is important to realize that there is no "one size fits all" solution, neither in the Global South overall, nor within a particular region. There are lots of factors that come into play as countries face all kinds of constraints in terms of availability of water and land resources, geographic and climate conditions, institutional and political frameworks, which often hinder efficient water resource management, and – most obviously – access to financial capital. The diversity of circumstances is even more pronounced at the subnational level, depending on the irrigation development capacities of regions and districts within a country. This poses a significant problem that hinders the expansion of sustainable irrigation in low-income and/or water-scares countries, which often face a mismatch in timing of water availability and of irrigation needs (Schmitt et al., 2022; Ai et al., 2021). A lack of secure access to land and water, effective institutional frameworks, and policies further decelerate the implementation of sustainable irrigation strategies in the Global South, at both national and regional levels (Nikolaou et al., 2020; Ofosu et al., 2014).

In this paper, we provide a thorough overview of the role played by irrigation in mitigating food insecurity, climate change, and migration at the subnational level. To limit the variation in circumstances and context, we focus on two specific cases: India in South Asia and Tajikistan in Central Asia, both among the world's most irrigated countries, with approximately 70% of the total cultivated area equipped for irrigation. These countries are often regarded as role models for other LMICs due to their significant irrigation coverage and the substantial foreign investments they receive, aimed at further enhancing their irrigation capacity.

However, solely relying on irrigation coverage figures may be highly misleading. Although over the last few decades India and Tajikistan have managed to create ample irrigation potential, they still face numerous challenges. A substantial portion of areas nominally equipped with irrigation are currently not being irrigated. (Pani et al., 2021; Ringler, 2021; Mukhabbatov et al., 2020). Timely addressing these issues is vital for India and Tajikistan, as both countries face food insecurity and environmental degradation, making them hotspots for climate-induced migration, due to increasing frequency and severity of droughts and floods that put rural livelihoods in jeopardy (WFP, 2017; Lukyanets et al., 2020).

While there is a growing body of articles and reports that discuss the opportunities and efficiency of irrigation in the Global South, the use of subnational data has been quite limited, mostly due to the scarcity of relevant statistics[1] Prior to commencing the work on this paper, we conducted an extensive data search and found that only a handful of countries in the Global South report subnational data on irrigation coverage. Furthermore, when such data exists, it most often covers only one or two years, which does not allow for examining changes in irrigation coverage over time. In this regard, India and Tajikistan represent important exceptions. They report relatively comprehensive subnational statistics on irrigation coverage, including its sources, techniques applied, water use efficiency, and other valuable metrics. The availability of this relevant data, coupled with high rates of irrigation coverage, was our primary rationale for slecting these particular countries for our comparative case study.

Besides the scarcity of research at subnational level, to our knowledge, it has not been fully explored how the efficient management of irrigation within countries can simultaneously address both economic and environmental issues, while considering various limitations they may face. Even less is known about irrigation as a climate change adaptation strategy vis-à-vis environmental migration, as this strand of literature is still in its infancy. Some emerging studies do report that irrigation can offset the effect of negative environmental changes on migration and especially internal rural-urban mobility (Benonnier et al., 2019). Therefore, including migration in our analysis is a valuable exercise aimed at – partially – addressing the lacuna in the literature and exploring how sustainable irrigation can benefit rural livelihoods.

1 Regional statistics may not be collected at all, they may be available only for some regions, or they may be not be compiled together in a national dataset.

In general, scholars tend to agree that irrigation can play an important role in the nexus between food security, climate change, and migration. However, the challenge lies in making it efficient, sustainable and equitable (Berhe et al., 2022; Singh, 2016; Mashnik et al., 2017). Therefore, in this paper, we attempt to bridge the gap between subnational statistics and scattered evidence from the literature, to develop a holistic strategy for the irrigation sector in India and Tajikistan that potentially could be applicable in other countries and regions of the world facing similar issues. Our findings are used to formulate policy recommendations that may enable informed decision-making for sustainable irrigation in the environmentally degraded and water-scarce future.

The remainder of this paper is structured as follows. Section 2 outlines the methodological approach. Section 3 discusses the broad socio-economic background of India and Tajikistan. Section 4 elaborates on the ramifications of climate change on water availability and the agricultural sector of these countries. Section 5 provides an overview of the development of water and irrigation systems in India and Tajikistan throughout the last decades. We perform a breakdown of irrigation governance systems by levels – national, regional, and local – and by areas of the country, in order to capture the spatial variation. Subsequently, Section 6 focuses on how the dynamics in countries' agricultural sectors and climatic conditions influence the migration aspirations of the population. Section 7 develops strategies for water conservation and improving irrigation efficiency, with special attention paid to the involvement of relevant stakeholders. Finally, we conclude the paper with proposed directions regarding the development of a holistic irrigation strategy for India and Tajikistan as well as implications for other countries in the Global South.

2. Methodological Approach

The topic of irrigation has been widely addressed in different fields of academic literature, including – but not limited to – agricultural science, development economics and climate science. However, most of the articles exploring irrigation in the Global South focus on evaluating irrigation development policies implemented either in a particular region of the world (e.g., Higginbottom et al., 2021, and Kadigi et al., 2019 for Sub-Saharan Africa; or Ahmed et al., 2022, and Hasanain et al., 2019, for South Asia), a particular country (e.g., Mwangi & Crewett, 2019, for Kenya; Wang et al., 2019, for China), or even a particular state (e.g., Sarkar et al., 2022, for the Punjab and West Bengal regions in India). Academic studies that examine the role of irrigation in several countries over time, at a regional or even local level, such as Higginbottom et al. (2021) and Palazzo et al. (2019), represent rare and important exceptions. With the aim of bridging the existing gap in the literature, we conducted an exploration of data sources available that would allow for a longitudinal cross-country subnational analysis.

The primary reason scholars have not yet examined the broader picture across many countries in the Global South is the absence of a comprehensive database on irrigation investments. The most complete dataset to date is the FAO AQUASTAT Database of subnational irrigation areas developed by the Food and Agriculture Organization of the United Nations. While the database includes the highly detailed Global Map of Irrigation Areas, it is not applicable for longitudinal analysis, as it is focused on the year 2005 (Siebert et al., 2005). FAO states that the reason why the database is not systematically updated is because "the update frequency of subnational data is erratic" (FAO, 2021). Nevertheless, finding such data was a crucial prerequisite for this study, because irrigation development tends to be uneven within countries (Mukherji et al., 2013; Srivastava et al., 2014). Capturing this spatial heterogeneity and its evolution over time was, therefore, a fundamental part of this study.

Hence, prior to commencing this paper, an exhaustive data search confirmed that only a handful of countries in the Global South report subnational data on irrigation coverage. We found that most governments in low- and middle-income countries (hereinafter LMICs) do not systematically compile irrigation statistics at the regional or district level. Moreover, while it is fairly common to find some estimates on irrigation coverage in agricultural censuses, these statistics only cover one or two years, hindering the examination of changes in irrigation coverage over time. In addition, when subnational irrigation statistics are present in academic literature, they are frequently of exceptional quality and offer intricate details. However, these statistics are typically derived from experimental studies conducted within specific villages, districts, or regions, limiting the ability to analyze spatial variations within countries.

In this regard, India and Tajikistan represent important exceptions, as they report longitudinal subnational statistics on irrigation coverage, including its sources, techniques applied, water use efficiency, and other valuable metrics. Therefore, irrigation statistics in these two countries cover both the time and spatial dimensions, aligning wit the main requirement of our analysis. The availability of such relevant data, coupled with high rates of irrigation coverage, was our main rationale for choosing these particular countries for this study. Having gathered relevant subnational statistics for the two countries, we conduct a comparative case study, aiming to narrow the knowledge gap in our understanding of the irrigation management frameworks these countries have in place and highlighting areas where coherent approaches are lacking. By employing regional and district-level data, we can observe how irrigation sectors have evolved over time in different areas within these countries and identify the determinants of this regional heterogeneity. At the same time, we focus on positioning irrigation management in a broader socio-economic and environmental context, to account for different kinds of constraints that countries and regions face in terms of availability of water and land resources, geographic and climate conditions or institutional and political frameworks.

Hence, in this article, our endeavor is to bridge the divide between the information provided by subnational statistics and the scattered evidence found in the literature. We seek to formulate a comprehensive strategy for the irrigation sector in India and Tajikistan, which could potentially be applicable to other countries and regions facing similar challenges. It is important to note that while no single country in the Global South, including India and Tajikistan, can serve as a representative example of sustainable irrigation development for the broader geographic region or the rest of the world, valuable insights can still be gleaned from examining country-specific cases, particularly when considering subnational variations.

Given the lack of reliable and comprehensive official statistics, this study draws on a wide range of literature, including – but not limited to – academic research papers, reports produced by international development agencies, official government documents, and databases, among others. Furthermore, since this study is a synthesis of existing research, its methodology is predominantly shaped by the accessibility and quality of secondary data. We acknowledge that in many cases the latest available statistics we employ are several years old; therefore, the inferences we make based on them must be handled with discretion.

3. Socio-economic Context

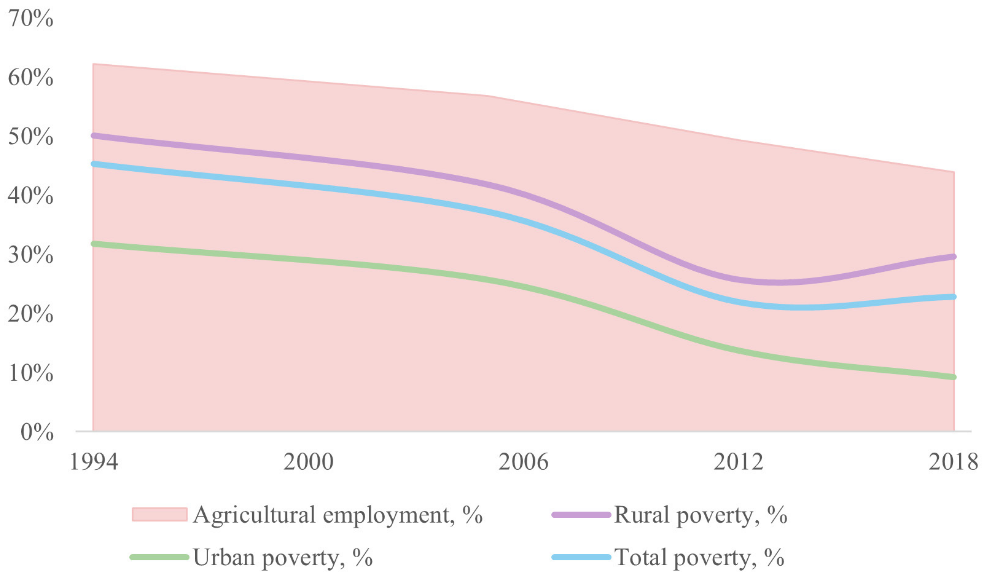
India and Tajikistan share certain key aspects – namely their significant dependence on agriculture, the persistence of rural poverty, and the rising environmental migration. This section sketches the socio-economic context of both countries, specifically focusing on the dynamics in the agricultural sector and socio-economic conditions of people involved in it. Keeping in mind that India is a generally better known and studied more extensively in the development economics literature than Tajikistan, we discuss the latter in more detail.

3.1 Agricultural sector and poverty in India

India, home to 17% of the world's population, faces challenges with limited global shares of land (2,4%) and water resources (4%). The per capita availability of usable water resources is rapidly decreasing due to growing demand for water and overexploitation of the country's water resources (CWC, 2016). The agricultural sector in India is responsible for 80% of the groundwater use (Harsh, 2017). A significant share of the 1.4 billion population of India relies on agriculture to sustain their livelihoods. While contributing significantly to the Indian Gross Domestic Product (GDP), the sector's share has been gradually declining over the past decades (Figure 1). At the same time, India experiences droughts that can lead to prolonged periods of water scarcity, and therefore pose a deleterious impact on the country's natural resources, crop cultivation, and environment (see Section 3.1). Moreover, considering the significance of the agricultural sector in the country, weather and climate extremes hamper food security, agricultural incomes, and the overall well-being of the people living in India (Kushwah, 2021).

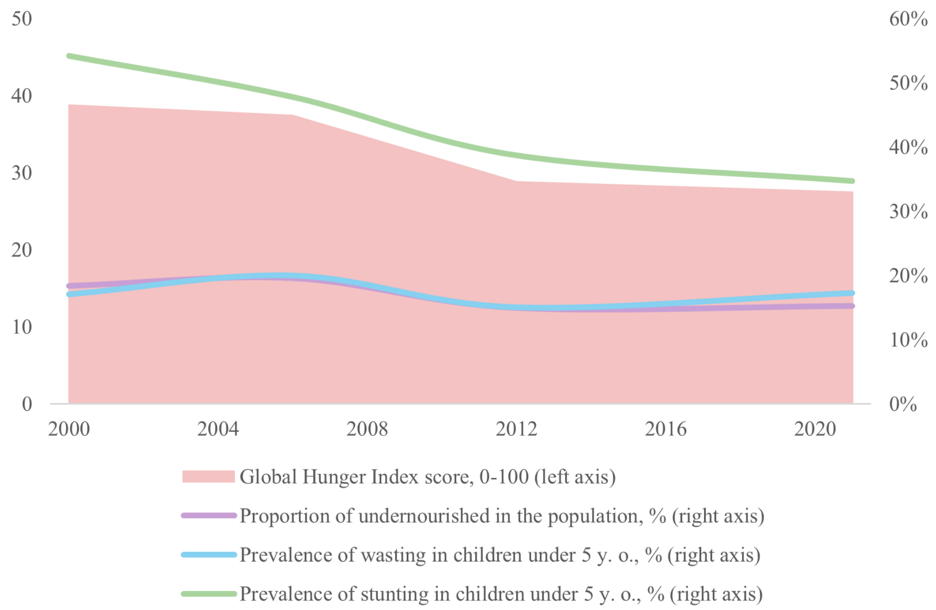
Worsening climate conditions, rising water scarcity, and increasing food production costs impact the incomes and livelihoods of the Indian population involved in agriculture, despite the significant amount of public funding and subsidies for the sector (Chuang, 2019; Sam et al., 2020; Shukla et al., 2019; Baniasadi et al., 2020; Bhattacharya & Devulapalli, 2019). Analysis of the consumption expenditure statistics reported by the National Statistical Office suggests that rural poverty rose almost 4 percentage points (p.p.) from 2012 and 2018, reaching 30%, while urban poverty decreased by 5 pp. to 9% over the same period

(NITI Aayog, 2021). Considering the larger size of India's rural population, the overall poverty rate grew by one percentage points, reaching 23% in the last ten years. This increase signifies that 30 million people fell below India's official poverty line in this respective period (Dhasmana, 2021).



Source: Constructed by the authors based on data from WDI Databank (agricultural employment) and the Indian National Statistical Office (poverty).

Figure 1: Dynamics of agricultural employment and poverty rates in India, 1994-2018



Source: Constructed by the authors based on data from Global Hunger Index (2022).

Figure 2: Food security and malnutrition in India, 2000-2021

Widespread poverty in the country also entails that, despite being one of the most self-sufficient countries in Asia in terms of domestic food production, India still struggles with ensuring economic accessibility of food for its population. Despite its efforts to manage the food economy through numerous public initiatives, including the Food Corporation of India and the Public Distribution System, India grapples with serious hunger levels, as per the Global Hunger Index that tracks hunger and malnutrition indicators across countries (Drishti IAS, 2022). Moreover, while its score has generally been improving, the country lags in the Index, slipping from 97th in 2016 to 101st in 2021 (Figure 2). A particularly striking level of malnutrition and wasting persists among Indian children.

With around 15% of the population undernourished throughout the last decade, India is now home to a quarter of all undernourished people in the world (WFP, 2022b). Despite numerous initiatives to address undernutrition, the problem persists and even worsens for certain groups; from 1992–2016, the prevalence of wasting in children increased from 17% to 21% (Khan & Mohanty, 2018). The issue of malnutrition is highly concentrated in certain states and districts, which have largely fallen behind any national progress (Kushwaha et al., 2020; Sahu et al., 2015).

Slow and uneven progress in combating hunger in the country partly owes to poverty and income inequality and partly to the inefficiencies in production and distribution of agricultural commodities, as well as challenges that arise from climate change. While per capita income more than tripled since the beginning of the century, the minimum dietary intake in India fell in average terms and is bound to keep falling unless India reforms its agricultural sector to mitigate deleterious effects of improper management and adverse climatic changes (WFP, 2022b; Narayan et al., 2019; Singh et al., 2019).

3.2 Agricultural sector and poverty in Tajikistan

Tajikistan is a small land-locked state in Central Asia. Due to its unique geographic and socio-economic conditions, the livelihoods of the country's inhabitants and their food security are highly affected by climate change (Gulahmadov et al., 2021; Murakami, 2020; Khakimov, 2019). The majority of Tajik people live in poverty in rural areas, highly dependent on agriculture and therefore particularly vulnerable to extreme climate events and the unpredictability of precipitation, with expected rising volatility (Babu & Akramov, 2022).

Among post-Soviet states, all of which are low- and lower middle-income countries, Tajikistan has the lowest GDP per capita and the highest poverty headcount ratio according to the World Food Program (WFP, 2022a). Moreover, being the world's most remittance-dependent country, it is extremely susceptible to external and internal economic shocks (WFP, 2017). While the country is highly dependent on imported food commodities, its domestic agricultural sector is still very important. For the last two decades, it accounted for a steady share of around a quarter of the country's GDP and employed almost half of its population (Figure 3).

For many years, the country has struggled with a severe food deficit and malnutrition among its citizens, in particular among children (Bakhtibeki, 2019; Kawabata et al., 2020). This is partly because, for decades, Tajikistan has been heavily reliant on food imports, which cover more than half of its population's nutritional needs. For instance, the country imports more than half of its consumed wheat, accounting for about 70% of the average daily caloric intake (McKee & Garrett, 2014). It puts the Tajik people in a highly vulnerable position with respect to global food prices and currency exchange rate fluctuations (Akramov and Shreedhar, 2012).

At the time of writing, due to its close economic ties with Russia and high dependence on food imports, Tajikistan is among the biggest victims of the global food crisis, with increasingly unstable imports and growing prices of agricultural commodities, including the main staples of Tajik consumption such as wheat, sugar, and oil (WFP, 2022a). The crisis exacerbates the preexisting major issue of food insecurity, with a large fraction of the population being unable to meet their nutritional requirements, according to the World Food Program assessment carried out in August 2021 (Figure 4). Another estimate provided by the Food Security Monitoring System shows even more disturbing evidence, stating that only 12% of Tajikistan's rural population is food secure, while 54% are marginally food secure, 28% are moderately insecure, and 5% are severely food insecure (WFP, 2016).

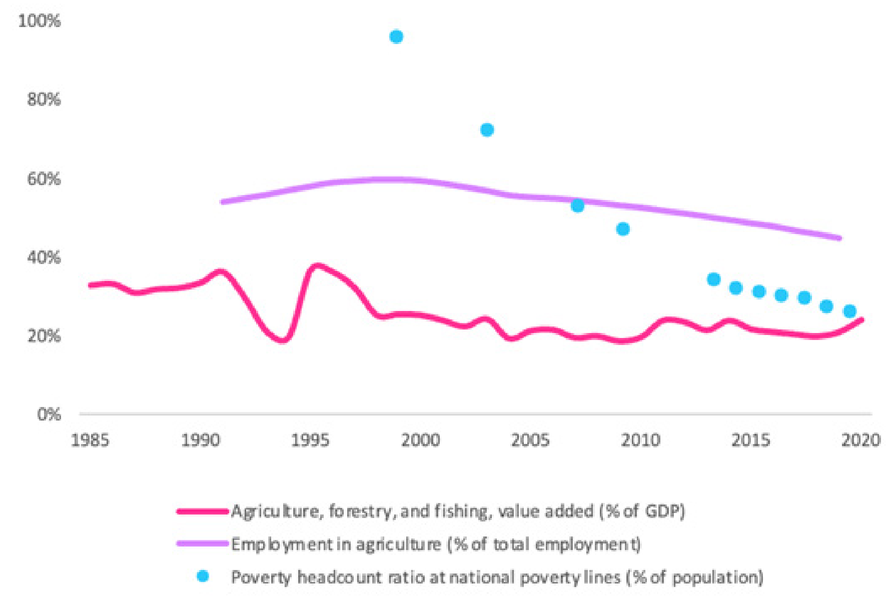


Figure 3: Agricultural sector and poverty statistics in Tajikistan, 1985-2020
Source: Constructed by the authors based on data from WDI Databank.(2022).

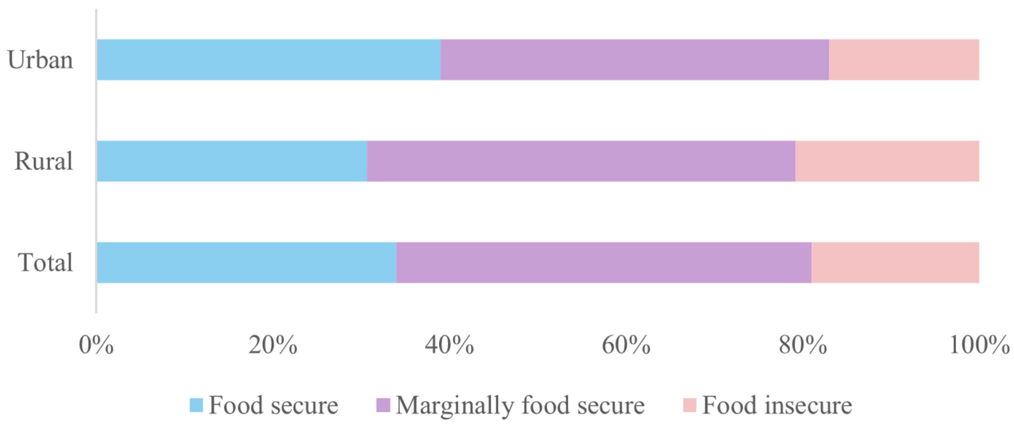


Figure 4: Food insecurity in Tajikistan in 2021
Source: Constructed by the authors based on data from World Food Program, 2022a.

Another facet of food insecurity is the economic dimension. The inability of the Tajik population to meet their nutritional needs is largely poverty-driven. For almost two thirds of people, buying food accounts for more than half of their total expenditures, and for 17% of the country's population, this share exceeds 75% (Figure 5) (WFP, 2022a). With prices for agricultural commodities presently rising, people in Tajikistan would have to give up on an even larger share of their income to buy food and sustain their livelihoods.

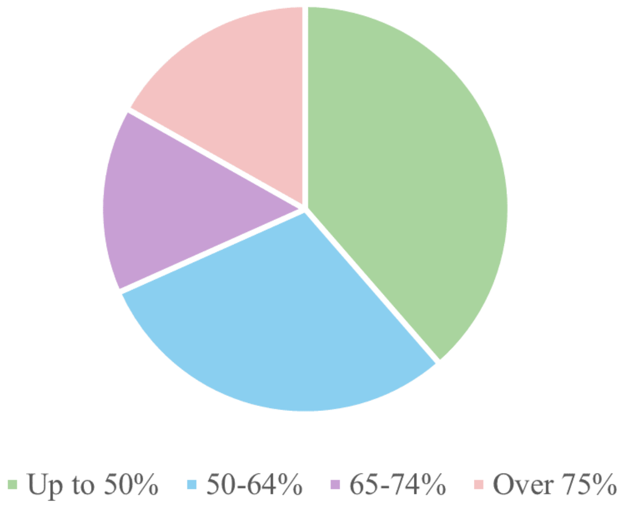


Figure 5: Distribution of households by share of expenditure on food
Source: Constructed by the authors based on data from World Food program, 2022.

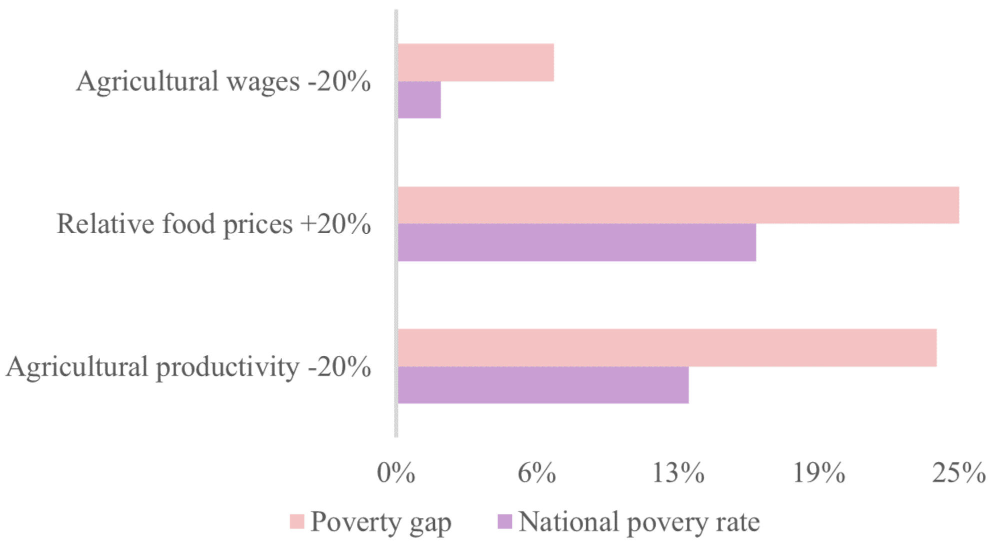


Figure 6: Impact of extreme climate conditions on poverty via agricultural productivity, wages, and commodity prices
Source: Constructed by the authors based on data from Heltberg et al. (2012).

Physical and economic dimensions that explain the lack of food security in Tajikistan are inextricably linked. As the Tajik population, especially in rural areas, is heavily dependent on agricultural production to support their livelihoods, the adverse impact of climate change leads to declines in agricultural productivity and the loss of harvests (Khakimov, 2019). As a result, household incomes suffer. A study conducted by the World Bank has estimated that a drop in productivity or wages in the agricultural sector by 20%, driven by adverse climatic events, could result in a 24% increase in the poverty gap and a 13% increase in the poverty rate (Figure 6). A similar 20% reduction in agricultural wages could also have a significant effect on poverty, albeit smaller in magnitude. The study found that a 20% increase in relative food prices due to extreme climate events was found to have the largest detrimental effect. One must be mindful that in a low-income country like Tajikistan, where population is highly concentrated around the poverty line, even a slight decline in incomes or purchasing power can have devastating consequences. Moreover, the largest impact is expected for the poorest households, ith the most limited access to agricultural technologies, infrastructure, and the lowest adaptive capacities (World Bank and ADB, 2021).

Among the various causes of limited food production in Tajikistan, climate change plays a crucial role, imposing both direct and indirect constraints on crop cultivation. Direct effects manifest through changes in carbon dioxide availability, precipitation and temperature patterns. Indirect channels include the growing demand for groundwater, especially in hotter and dryer periods, as well as the declining availability and quality of cultivable lands due to soil erosion and desertification (Closset et al., 2015). For instance, in the Khatlon province, climate change has significantly exacerbated food insecurity by causing irrigation infrastructure to fall into disrepair, thereby producing declines in agricultural productivity and depriving rural livelihoods of food and incomes (WFP, 2017; Kodirov et al., 2020).

From the contextual overview presented above, it is evident how India and Tajikistan face very similar challenges when it comes to ensuring food security and decent economic conditions for their population, especially those involved in the agricultural sector. Considering that India – unlike Tajikistan – is quite self-sufficient in its food production capacity, simply expanding domestic agricultural production is clearly not a solution for these challenges. A broader set of factors – particularly with respect to water and irrigation management – must be considered in to understand how to tackle food security and rural poverty in India and Tajikistan.

4. Water Resources and Agriculture in the Context of Climate Change

Due to the specifics of their geographic locations, both India and Tajikistan are extremely susceptible to climate-related hazards, including both the increasing frequency of sudden onset climatic events like droughts and floods, as well as slow onset or gradual changes in weather and precipitation patterns. In this section, we provide an overview of how climate change affects water availability and agricultural productivity in both countries. To facilitate a nuanced exploration, India and Tajikistan will be discussed separately, acknowleding distinctions in their land and water endowments and the climate-related challenges they face which are different in many aspects. Furthermore, in this analysis we consider regional disparities within the countries, because different regions of India and Tajikistan have varying degrees of exposure to water stress and adverse climatic shocks.

4.1 Agricultural sector and poverty in Tajikistan

The frequency of drought occurrence has significantly increased in India (Mishra, 2019; Mallya et al., 2016). Over the last four decades, the country has experienced a major drought at least once every three years (Rasul, 2021). The period between 1950 and 1989 experienced 10 drought years, defined by the India Meteorological Department (IMD) as years with overall rainfall deficiency greater than 10% of long-term average and spatial coverage of the drought greater than 20% (IMD, 2021). In contrast, the last two decades alone have borne witness to six droughts, Three of these six recent droughts that appear in Figure 7 below can be categorized as “major” based on their severity (bubble size) and duration (vertical axis). Drought severity is computed from the drought’s mean intensity and mean areal extent; the largest bubbles highlighted in purple show the most severe and devastating droughts of the last two centuries, two of which happened within the last 15 years. According to meteorologists, the frequency and severity of drought events is set to increase even more between 2020 and 2049 (Mishra et al., 2020b).

Recurring droughts in India cast a pervasive impact on food production, GPD, livelihood, and the socio-economic conditions of a large population associated with agriculture (Zhang et al., 2017). The recent 2015–2018 drought caused groundwater depletion and affected about one-fourth of the Indian population (Mishra et al., 2021a; Gogoi and Tripathi, 2019).

The occurrence of droughts and food security is inextricably linked. Drought-prone districts comprise nearly 42% of the country's cultivable lands (see Figure 8 for an overview of the different climate zones of India). Rainfed agriculture, especially in these areas, still plays a vital role in the country's economy, with 68% of India's net arable area being rainfed (Mishra et al., 2021b). Moreover, rainfed crops account for almost half of the area of food grain cultivation and two-thirds of the area dominated by non-food crops, as reported by the National Rainfed Areas Authority. Nearly 50% of the rural workforce lives in these areas.

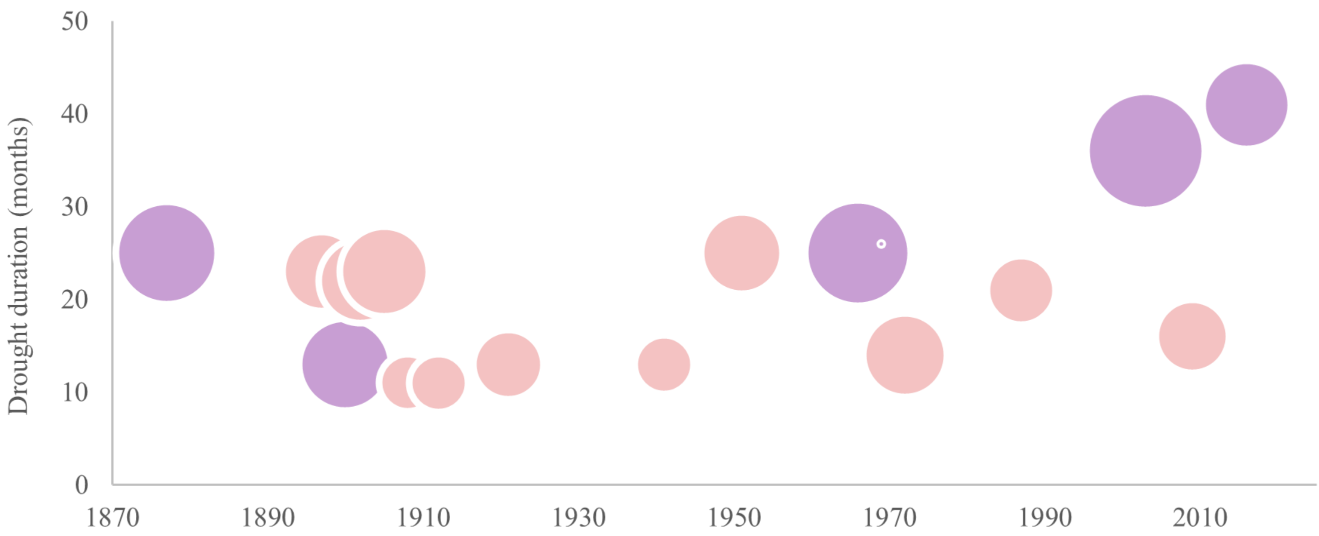


Figure 7: Major droughts in India in 1870-2018
Source: Constructed by the authors based on data from Mishra, 2019.

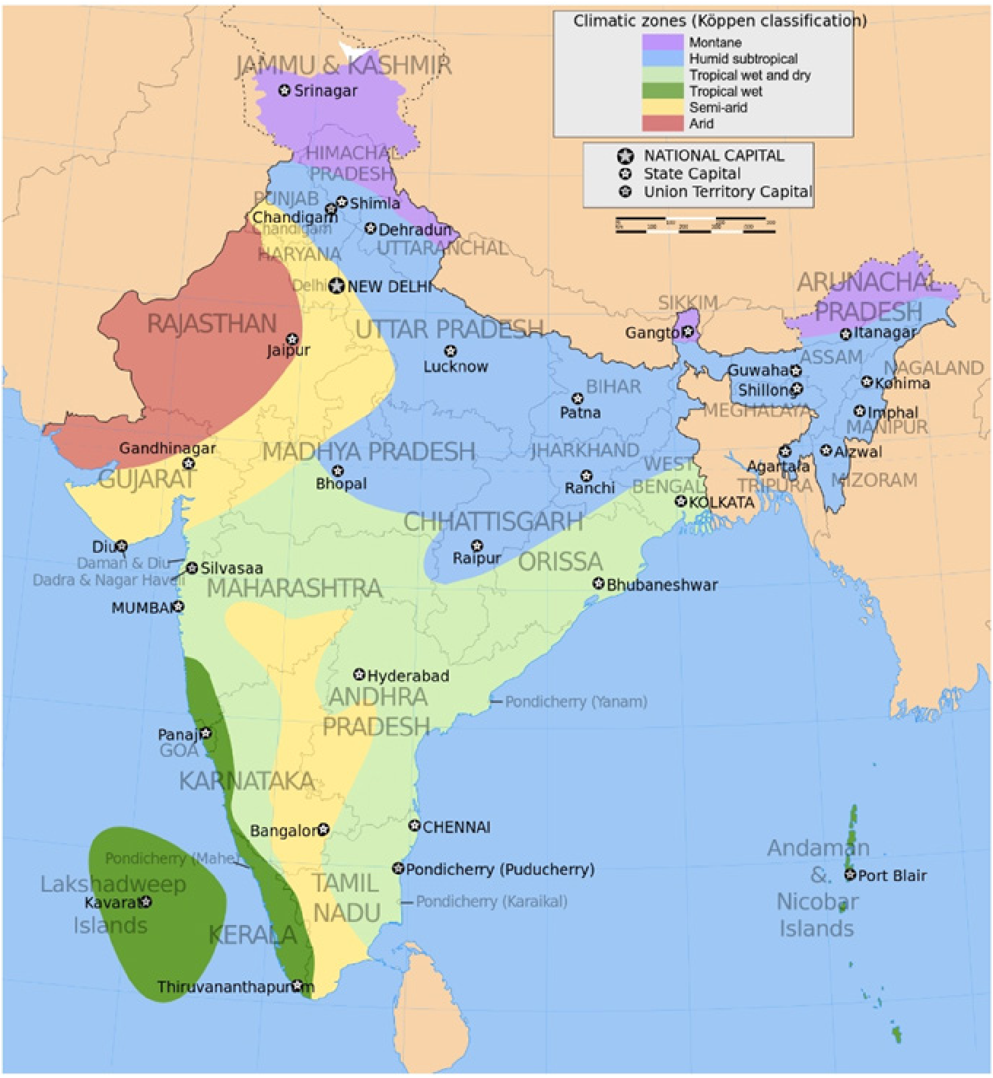


Figure 8: Major Climate zones of India
Source: Saravask, 2020, based on work by Planemad and Nichalp.

Apart from the increasingly frequent droughts, climate change also causes the recession of glacier and snow covers in the Hindu Kush Himalaya mountains, leading to changes in the mountain runoff, rising temperatures, and shifting precipitation patterns (Immerzeel et al., 2020). In terms of precipitation, India primarily relies on the southwest monsoon rainfall that accounts for 75–90% of the total annual rainfall (Varikoden et al., 2019). During the monsoon season, rainfall water is collected in reservoirs to secure water supply for agriculture, industry, and drinking water throughout the whole year (Thatte, 2017). However, in the last decades, monsoon rainfall has been falling, leading to severe water shortages that in turn resulted in lower crop yields (Ghosh et al., 2016; Barik et al., 2017; Asoka et al., 2018).

This negative dynamic is particularly evident in the most drought-prone regions, i.e., Northern Karnataka, Southern and Eastern Maharashtra, Andhra Pradesh, Odisha, Telangana, and Rajasthan, which altogether cover more than 60% of the country (Thrippakkal et al., 2021). For instance, the delayed monsoon in 2012 spiked the demand for energy to pump groundwater for irrigation, resulting in a hydropower shortage and blackouts (Barik et al., 2017). Northwest India, often called India's breadbasket with its large production of rice and wheat, has also experienced severe groundwater stress because of the increased water demand for irrigation (Gulati et al., 2019).

Increasing groundwater extraction during droughts can help the farming population to survive such critical climate events (OECD, 2016). However, this strategy leads to groundwater overexploitation and decline in quality, so that the amount of groundwater available for agriculture is decreasing, thereby posing an even bigger threat to future agricultural production (Devanand et al., 2019; Mishra, 2019). Between 2004 and 2017, state-wise groundwater depletion rate rose in almost every region of the country (Figure 9). Gujarat was the only exception, as it restricted the power supply to agriculture through Jyotigram Yojana scheme in 2006 (Bird et al., 2014; Biswas-Tortajada, 2014). Groundwater overuse reaches dangerous levels especially in northwestern and southern India; as of 2017, the states of Punjab, Rajasthan and Haryana have exceeded the replenishable rate of groundwater withdrawal. The eastern states of India have mostly managed to maintain a safe rate of groundwater withdrawal at about half of its natural replenishing capacity.

However, at the national level, the dynamics remain deeply troubling; since the beginning of the century, India has accounted for 23% of the increase in global groundwater depletion for irrigation (Dalin et al., 2017). Bringing groundwater exploitation to a sustainable level is essential for the country to protect its ecosystems and ensure food and water security for its population in the current and projected future climate (Dangar et al., 2021; Baniasadi et al., 2020). Therefore, future droughts are expected to be disastrous for the country, if it continues to heavily depend on groundwater to meet its agriculture and drinking water needs (Mishra et al., 2020a).

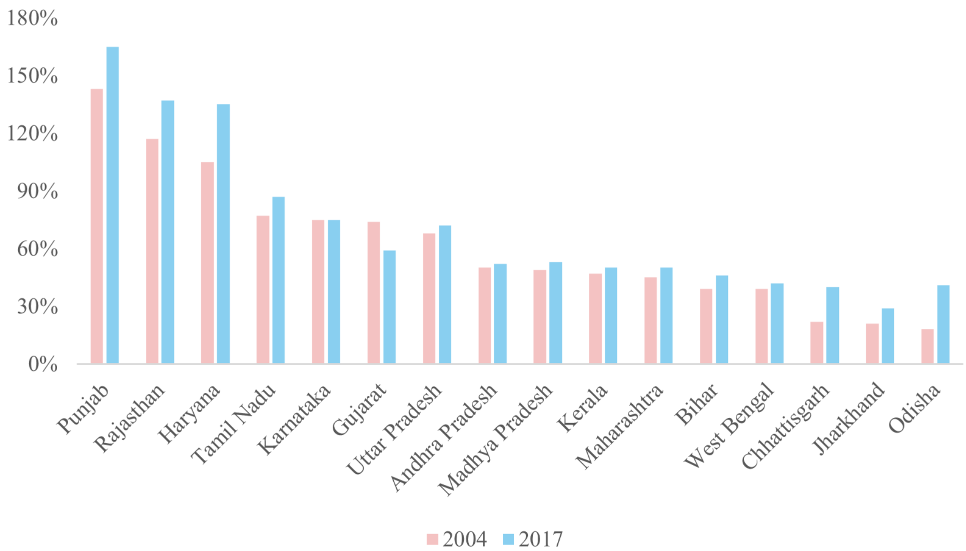


Figure 9: State-wise groundwater depletion, 2004 and 2017 (% of net availability)
Source: Constructed by the authors based on data from Shivaswamy et al., 2021.

4.2 The effect of climatic shocks on water availability, agriculture and the population in Tajikistan

Tajikistan, often referrred to as the "water tower" of Central Asia, boasts abundant water resources, including lakes and rivers. (Mukhabbatov, 2020; UNFCCC, 2014). The glaciers in the Pamir mountains are vital for water availability, agricultural supply, and hydropower generation (World Bank, 2020b). Moreover, the glaciers play a vital role in the climate regulation both in Tajikistan and the entire Central Asian region (World Bank and ADB, 2021).

However, climate change is causing unsustainable glacial retreat and snowmelt, leading to a loss of glacial mass and a reduction in water availability (White et al., 2014). From the mid-twentieth century until the beginning of the 21st century, the country lost 17% (1.4 thousand km2) of glacier-covered area and 30% of glacial mass (Kayumov, 2018; Pfefferle et al., 2020). Mudflows and floods stemming from erratic snowmelt can cause substantial damage to rural and mountainous areas, as well as a deficit of water resources in arid areas (Aliyev, 2021). Moreover, losing glaciers for Tajikistan means losing its natural water reservoirs without having sufficient water storage capacity (Zhongming et al., 2022b; Zhao et al., 2020). Over time, it increases the risk of water deficits, droughts, and desertification, posing a significant threat to the economy and population (World Bank and ADB, 2021; Liu et al., 2019; Pannier, 2021).

What makes Tajikistan so highly susceptible to climate change is that, similarly to India, its climate conditions are extremely diverse, ranging from both cold and hot semi-arid and desert zones to areas with humid subtropical climate (Figure 10). The country's scarce and low-productivity cultivable land – limited to only 840 thousand hectares – is highly dependent on irrigation to offset the unfavorable and volatile weather conditions (Mukhabbatov et al., 2020; Nasriddinov et al., 2021; Central Asian Bureau for Analytical Reporting, 2021; ADB, 2020). Future projections indicate rising temperatures, volatile precipitation patterns, and increasing water demands for crops, leading to imbalances in the irrigation system and water scarcity (White et al., 2014; Kobuliev et al., 2021; Pfefferle et al., 2020; Khakimov, 2019). The climatic constraints for crop cultivation are likely to increase over time, as Tajikistan is expected to experience temperature rises significantly above the global average, Scholars estimate that, under the highest emissions scenario, warming could reach 5.5°C by the end of the century, in comparison to the 1986–2005 baseline (World Bank and ADB, 2021). It makes the existing desert and arid areas even hotter and dryer while causing glacial melting and recurrent large-scale flooding in mountainous areas (Figure 11) (Hu et al., 2019).

The agricultural sector, particularly rainfed crops and pastures, is the most profoundly affected (World Bank, 2020a). For instance, the production of rainfed wheat crops was almost entirely destroyed due to the severe agricultural drought in 2000, which resulted in a 17% loss in agricultural GDP. Irrigated crops were affected less but still substantially, with a 30-50% crop failure rate (Thurman, 2011). This drought plunged two-thirds of the country's population in a position of extreme food insecurity (ADRC, 2019). As for flooding, about 40% of the Tajik population faces a high flood hazard (Figure 12). Tajikistan's poorest population is disproportionately affected by climate change, as they are concentrated in arid and semi-arid areas and lack the means to protect their livelihoods (Zhang et al., 2020; Cao et al., 2023). The economic impact of these hazards is substantial, amounting to an average annual GDP loss of $100 million (Figure 13). The province at greatest risk of floods is Badakhsoni Kuni, or GBAO, which is also the poorest province in the country, making the flood-induced economic losses extremely dangerous for people's welfare (World Bank and GFDRR, 2016).

The analysis presented above shows how Tajikistan and India both face similar challenges related to droughts and erratic precipitation, but Tajikistan's vulnerability is amplified by glacial snowmelt and flooding. As both countries have relatively low levels of disaster preparedness and unsustainable approaches to water management (which we will demonstrate in the following section), their agricultural productivity and the livelihoods of rural populations remain unprotected from climate-related hazards, which is an issue to be urgently addressed.

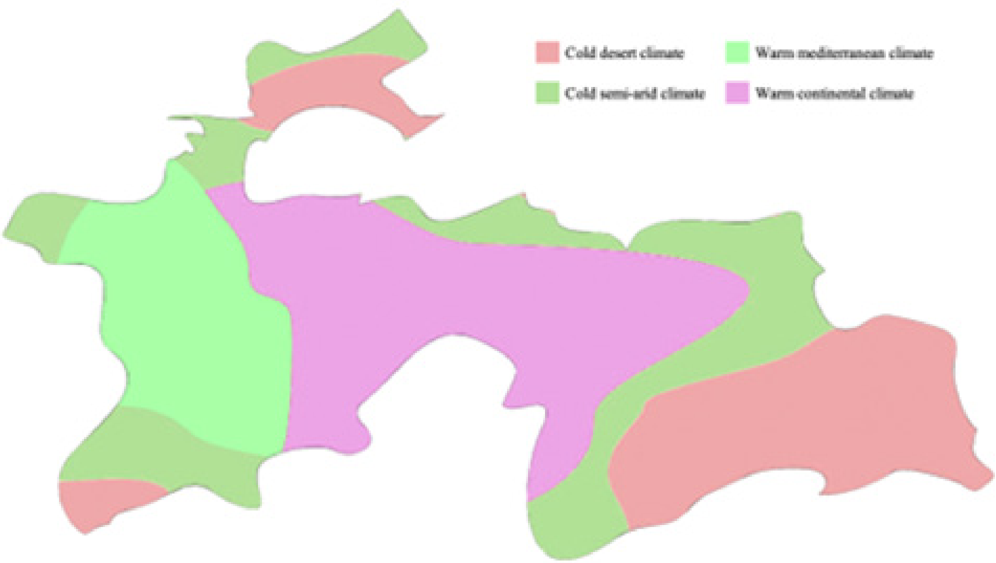


Figure 10: Climate zones of Tajikistan
Source: Constructed by the authors based on the map by Zifan, 2016.

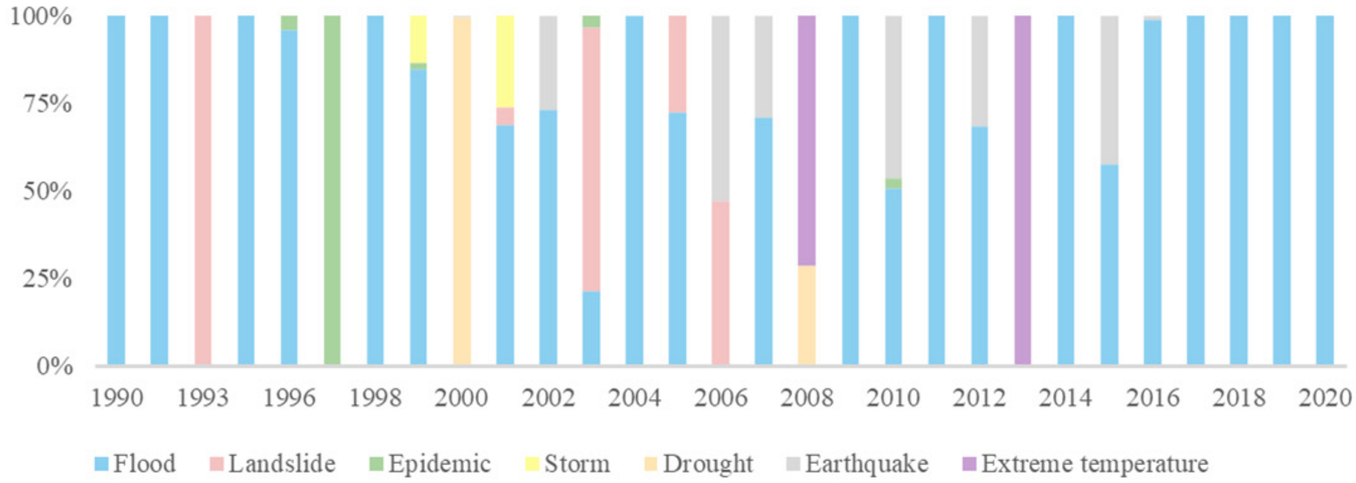


Figure 11: Share of various natural hazards in Tajikistan, 1990-2020
Source: Constructed by the authors based on data from Climate Change Knowledge Portal, 2022.

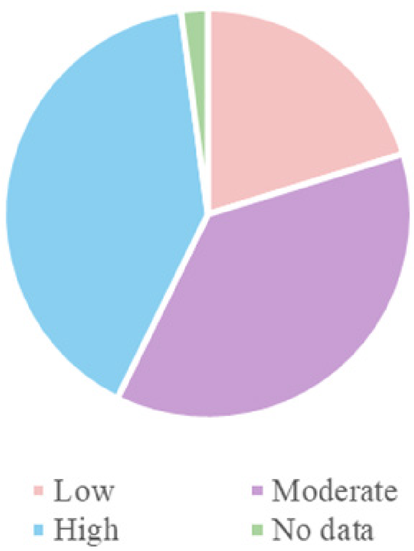


Figure 12: Population shares by exposure to flooding hazard
Source: Constructed by the authors based on data from CAC DRMI, 2009

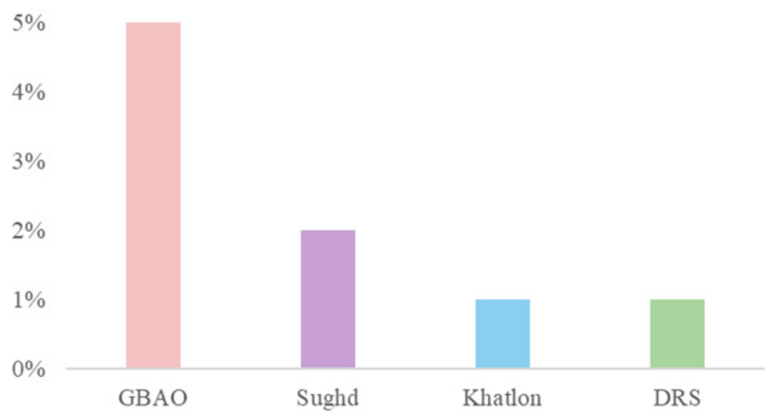


Figure 13: Annual average percentage of GDP affected by flood by region
Source: Constructed by the authors based on data from the World Bank and GFDRR, 2016

5. Water and the Irrigation Sector

In the broad discourse on climate-smart agriculture, expanding irrigation is a recurring topic because of its potential for improving efficiency and precision of water use. India and Tajikistan often act as benchmarks for other countries in the Global South, havingachieved relatively high irrigation coverage through dedicated public initiatives and ample investments from foreign development agencies (Parween et al., 2021; Asher et al., 2022; Arabov & Sharipov, 2021; Zhongming et al., 2022a).

However, a closer examination of both countries' approach to water and irrigation governance, reveals all kinds of deficiencies that keep them from utilizing water resources and irrigation infrastructures in the most efficient and sustainable way. Especially now that both India and Tajikistan are becoming increasingly affected by climate change reducing their water availability and agricultural productivity, addressing these deficiencies is crucial to protect their population from water stress and food insecurity (Rao and Anitha, 2021). In this section, we compare the approaches towards irrigation management in India and Tajikistan, respectively – and the challenges faced by these countries. The multi-level governance framework is employed, where we break down the irrigation governance structures into national, regional, and local levels, with the aim of identifying areas where policy action could be taken.

5.1 Water and irrigation governance in India

In the last decades, the Government of India has placed greater emphasis on responsible water management and conservation. In line with this vision, the Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) has been developed, with two primary objectives: extending the irrigation coverage 'Har Khet ko pani' and improving water use efficiency 'More crop per drop' (see Figure 14 for an overview of the PMKSY program design). The program operates in a focused manner, designing solutions for the creation, distribution and management of water resources in the country (Government of India, 2022).

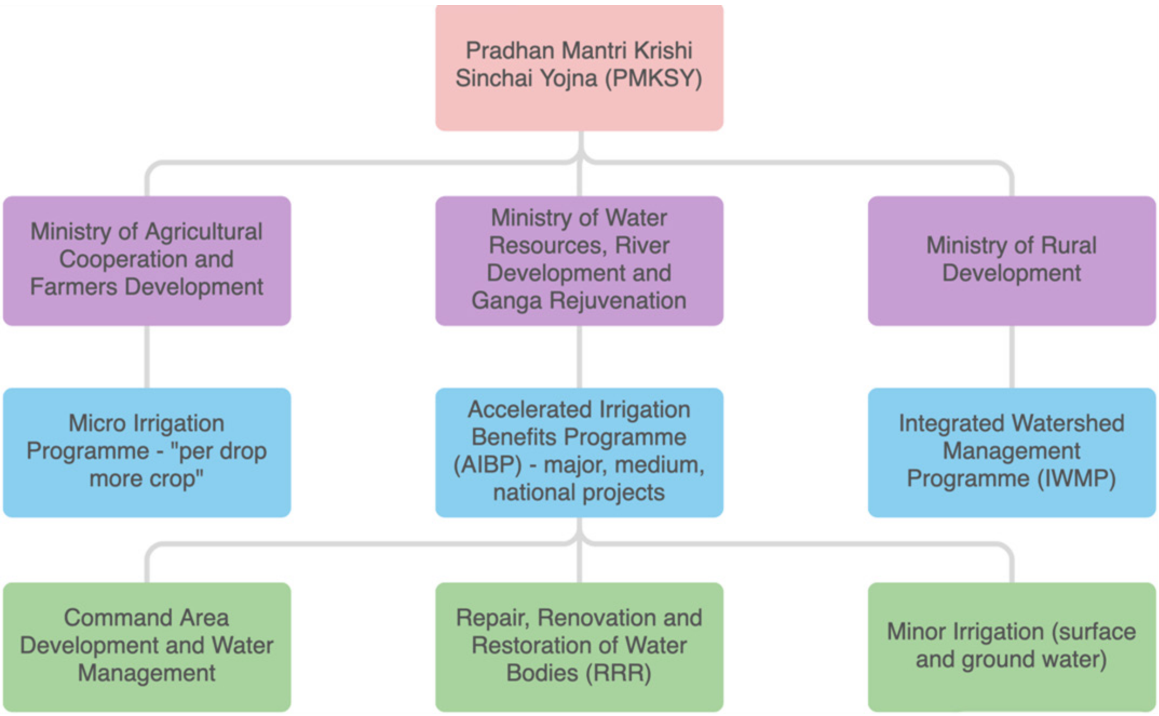


Figure 14: The Pradhan Mantri Krishi Sinchayee Yojana program design
Source: Constructed by the authors based on data from the Government of India, 2022.

The PMKSY program represents a consolidation of several ongoing schemes, namely the Accelerated Irrigation Benefit Program (AIBP) of the Ministry of Water Resources, the River Development & Ganga Rejuvenation, the Integrated Watershed Management Program of Department of Land Resources, and the On Farm Water Management of Department of Agriculture and Cooperation (Vohra and Franklin, 2020). The PMKSY program has been approved for implementation across the country in 2015 with a planned outlay of Rs. 50,000 crores ((US$ 7.7 billion) in ten years. With this integrated approach, the projects' completion rate improved significantly (Figure 15).

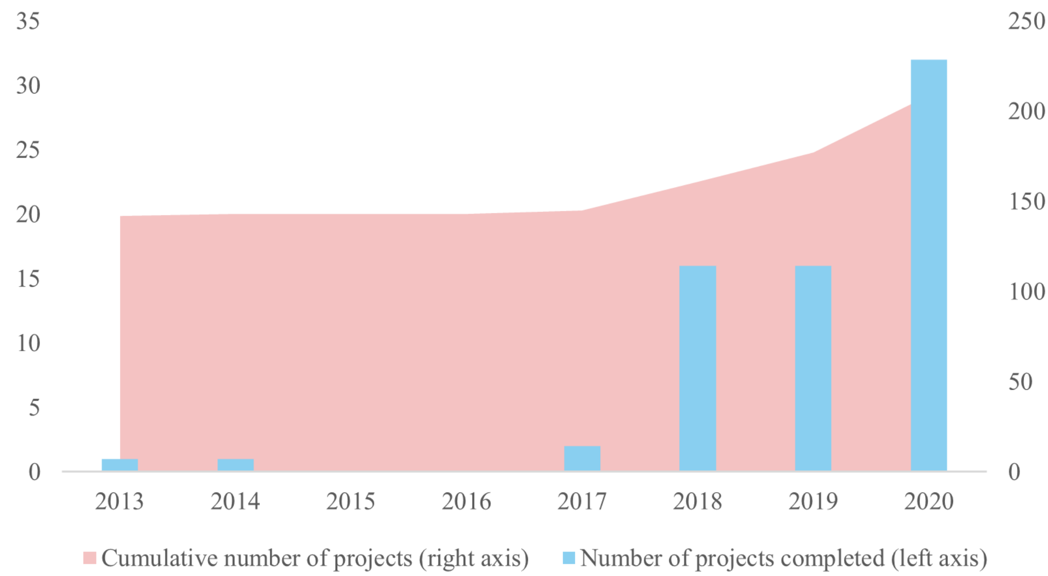


Figure 15: Irrigation projects' completion rate between 2013-2020
Source: Constructed by the authors based on data from Vohra and Franklin, 2020.

Indian authorities overseeing water and irrigation collaborate at the central, regional, and local level (Dhawan, 2017). The Central Water Commission is primarily engaged in promoting integrated and sustainable approaches to developing and managing the country's water resources, with a special focus on state-of-the-art technology and coordination of all stakeholders. The Central Ground Water Board was set up to develop and disseminate technologies concerned with groundwater resources, in accordance with principles of economic and ecological efficiency and equality. Together, the Central Water Commission and Central Ground Water Board have proposed the 'General Guidelines for Water Audit and Water Conservation'. These guidelines have been distributed to all the state governments and related central ministries.

Besides the federal government, state governments in India also undertake large public investments in construction, modernization, and rehabilitation of irrigation systems (Biswas et al., 2017; Thatte, 2017). Research indicates that areas of the country that invested in surface irrigation have achieved higher yields, imrproved cropping patterns, expanded gross cultivated areas, and shifted from mono-crop regimes to double-cropping, compared to districts that remained dependent on rainfed agriculture (Kumar, Jagadeesan, & Sivamohan, 2014).

As per the sources of irrigation, since 1950, the Government of India had been actively investing in the development of canal irrigation (Tiwari and Ankinapalli, 2013). While in 1950, 8.3 million hectares were irrigated by canals, by 2017, the canal-irrigated area reached 16.18 million hectares (Dhawan, 2017). On the other hand, territories irrigated by wells and tube wells comprised 29% of the total irrigated area in 1950, and now they share two-thirds of the total irrigated area. Despite the doubling of canal-irrigated areas, the relative importance of canals has been steadily declining from 40% in 1951 to 23% in 2016 (Singh and Tilak, 2022), while the area under groundwater irrigation has been on rise, which is a matter of concern, given the alarming rate of groundwater depletion in many states (Figure 16).

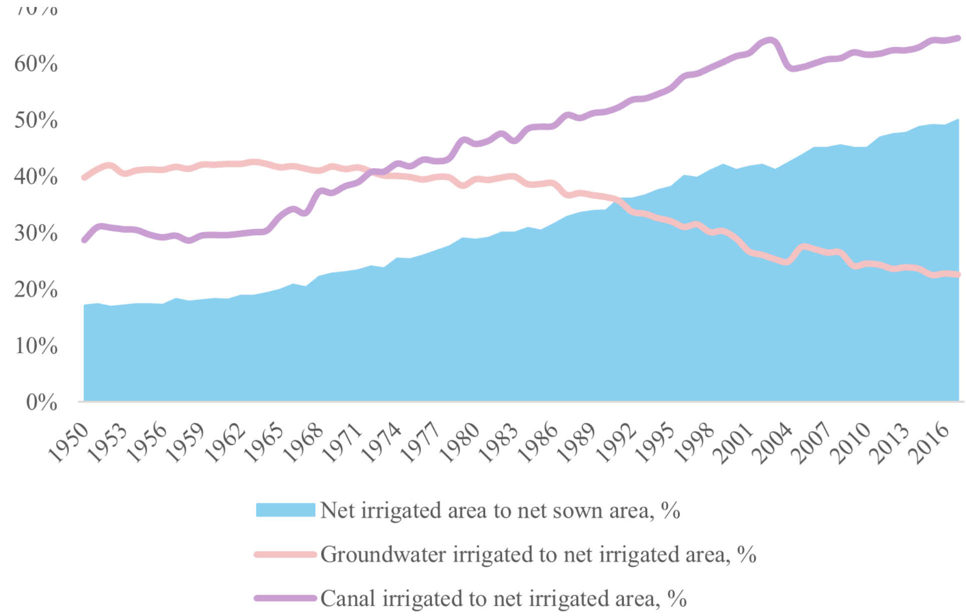


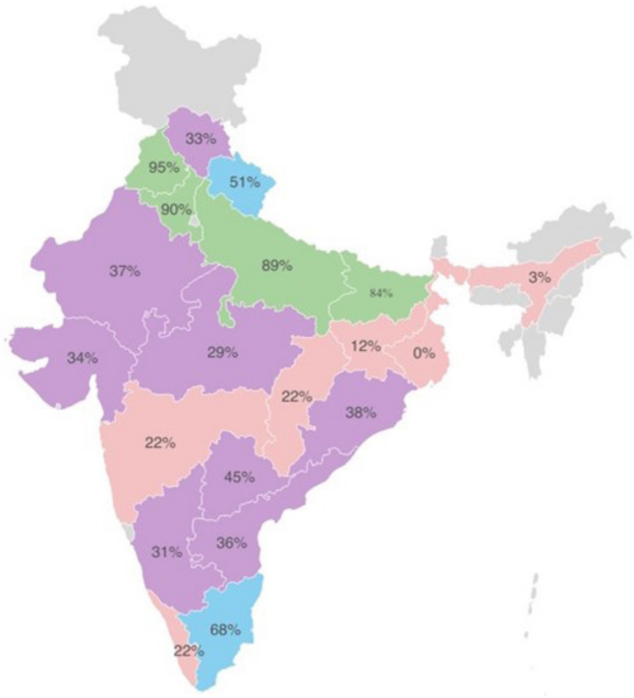
Figure 16: Dynamics of net irrigated area, total and by source, in 1950-2016
Source: Constructed by the authors based on data from the Government of India, 2021 (net irrigated area) and the Reserve Bank of India, 2020 (net sown area).

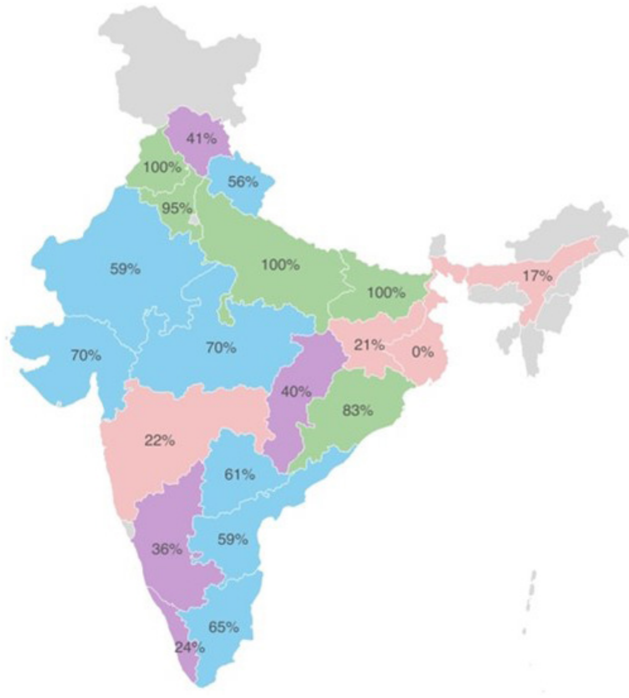
Besides the national and regional initiatives, like many countries around the world, India recently started practicing the transfer of irrigation management from the government to the local farmers with an expectation of improving the efficiency and sustainability of irrigation systems (Khandker et al., 2020). However, until the present day, their participation in water governance remains very limited. Local water users often are not only excluded from decision-making processes but also lack the necessary skills and knowledge to efficiently manage the irrigation infrastructure (Yadav et al., 2019). The absence of appropriate training hinders the adoption of irrigation systems and leads to persistent inefficiencies in their functioning (Chaudhari, 2021).

5.2 Present state of irrigation in India

Figures 17 and 18 depict district-wise irrigation coverage in India in 2005 and 2016, respectively. We can see that, while the country overall has made considerable progress in creating irrigation potential, there is substantial regional heterogeneity. Certain states in western and central India have shown considerable improvement in the irrigation coverage; the best performers were Madhya Pradesh (41p.p. increase), Orissa (45 p.p. increase), Gujarat (36 p.p. increase), and Uttar Pradesh (25 p.p. increase).

Some states, on the other hand, have shown little to no progress in improving irrigation coverage. These include the southern states of Kerala (3 p.p. increase), Karnataka (5 p.p. increase), Tamil Nadu (3 p.p. decrease), the northern state of Uttarakhand (5 p.p. increase), and West Bengal, which has remained at an extremely low level of irrigation coverage. So, while the national average improved quite substantially from 50% to 64% over the observed period, many states are still lagging far behind this average value.





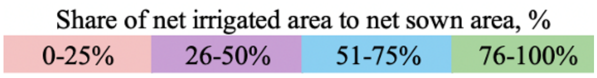


Figure 17: Irrigation coverage in 2005
Source: Constructed by the authors based on data from ICRISAT, 2020.

Figure 18: Irrigation coverage in 2016
Source: Constructed by the authors based on data from ICRISAT, 2020.

One reason for the interregional variations in irrigation coverage is that states and districts that receive enough precipitation mostly adhere to rainfed cropping systems. Given the diversity of India's climate zones exhibited earlier in Figure 8, different states are exposed to completely different rainfall and temperature patterns. With respect to agriculture, this variability results in distinct needs for irrigation. Figures 19 and 20 below show state-wise water requirements reported by the National Commission for Integrated Water Resource Development for 2010, as well as a forecast for 2050 (Srinivasrao et al., 2015). The north-western and eastern states that have a predominantly humid subtropical climate appear to have the lowest water requirements, since they receive sufficient rainfall. Consequently, one might expect that these regions may have less irrigation coverage. This holds true for some eastern states like Assam, Jharkhand, Chhattisgarh, and West Bengal. However, the states of Bihar (north-east) and Haryana (north-west) with modest water requirement, have India's highest rates of irrigation coverage.

In regions with higher irrigation water needs such as Uttar Pradesh, Uttarakhand, Rajasthan (all north), Andhra Pradesh and Tamil Nadu (both south-east), characterized by mostly semi-arid climate, there is a notable correlation between high irrigation coverage and water requirements. The notable exception here is Maharashtra – the region in central India that has a relatively high-water requirement due to the combination of semi-arid, tropical dry and wet climate, but one of the country's lowest levels of irrigation coverage. Other states with moderate needs for irrigation water tend to have 50-75% of land equipped with irrigation, which might be sufficient in combination with rainfed agriculture. However, even in regions where the amount of precipitation is enough to serve the agricultural sector, creating irrigation infrastructure can still be beneficial for rainwater harvesting, storage, and distribution (Velasco-Muñoz et al., 2019). Especially now, with temperature and rainfall fluctuations becoming erratic due to climate change, absence of adequate irrigation infrastructure can lead to disruptions in water supply to command areas, which leads to productivity and income losses (Odhiambo et al., 2021; Banerjee & Duflo, 2007).

Development of reservoir storage capacity is a crucial component of ensuring smooth water supply for irrigation in the face of climate change (Tiwari & Mishra, 2019; Bhanja & Mukherjee, 2019; Ai et al., 2021). Apart from different needs for irrigation across states driven by rainfall distribution, interregional disparities in irrigation coverage can be explained by several constraints faced by states. Firstly, state-wise differences in groundwater endowments impose a physical restriction on the amount of water available for irrigation. Secondly, there is considerable variability in the amount of public funds earmarked for creating irrigation potential, i.e., the total gross area proposed to be irrigated under different crops during a year by a scheme (MoWR, 2016). This heterogeneity is driven by the different scale and cost of irrigation projects (Figure 21). In some states, particularly in the south of India, the share of real investments in total public financing is relatively higher, due to significant time and cost overruns, and overall lower efficiency of irrigation projects (Shivaswamy et al., 2021).

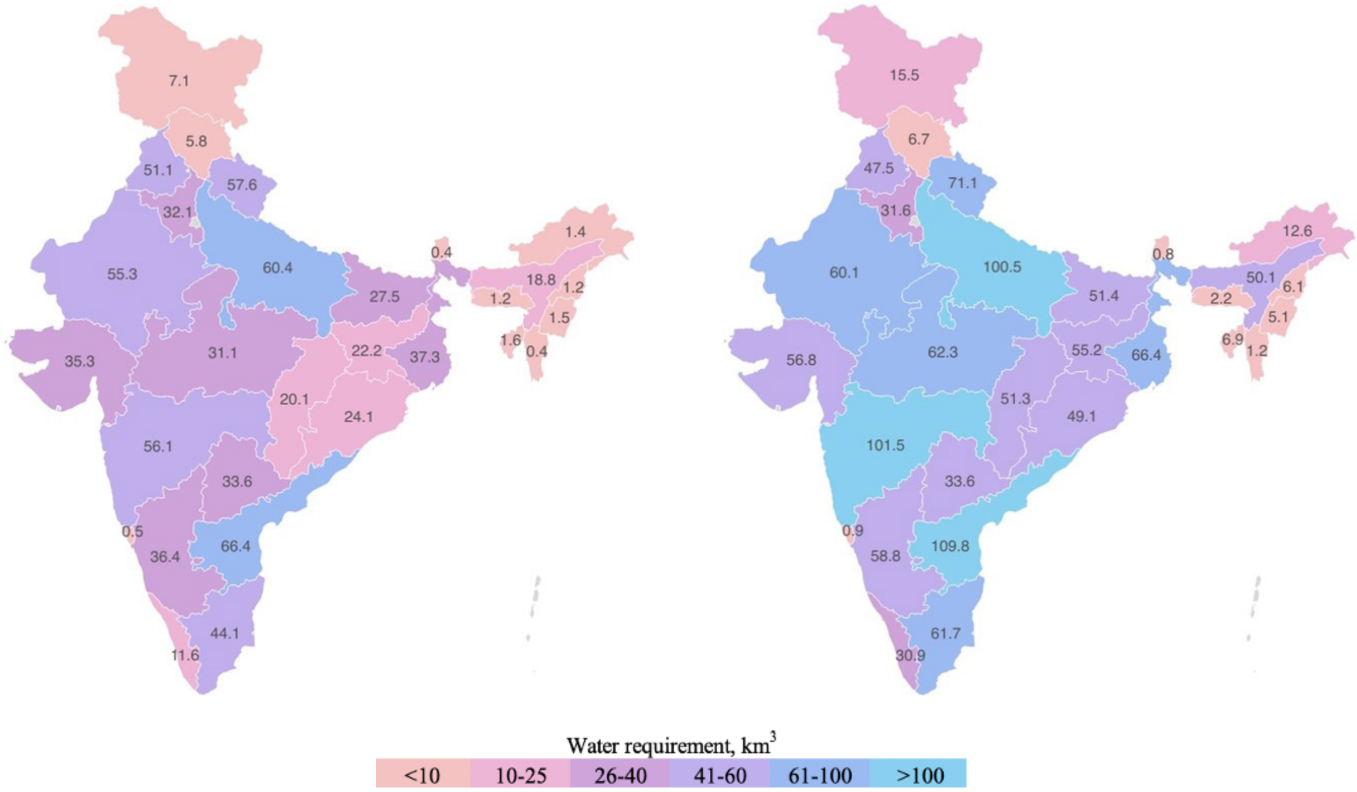


Figure 19: Water requirement, km3 (2010)
Source: Constructed by the authors based on data from Srinivasrao, 2015.

Figure 20: Water requirement, km3 (2050)
Source: Constructed by the authors based on data from Srinivasrao, 2015.

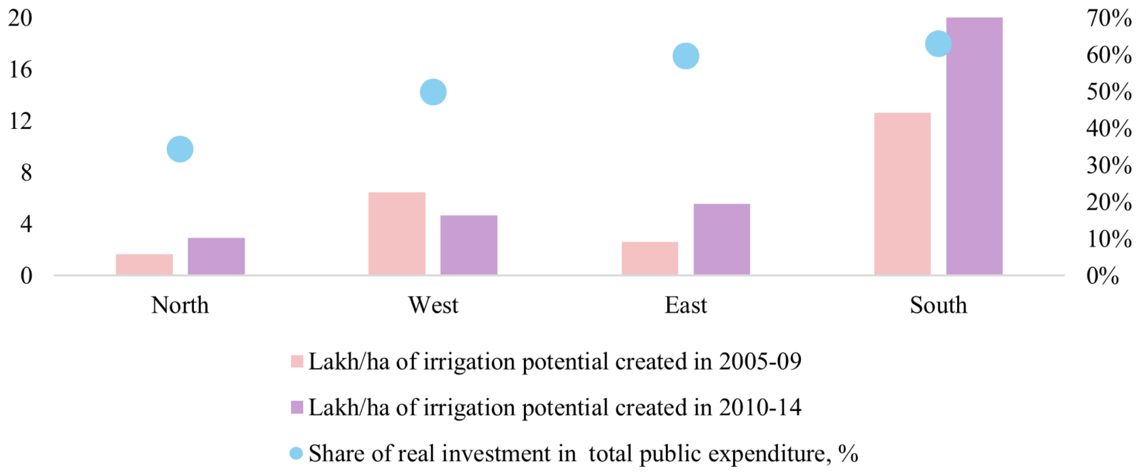


Figure 21: Cost of irrigation potential created per hectare in India, by state
Source: Constructed by the authors based on data from Shivaswamy et al., 2021.

In fact, despite the large number and scale of irrigation investments in India, the effectiveness of public capital expenditures on major and medium irrigation projects, as well as their returns, varies considerably depending on location, remaining a matter of concern (Kannan et al., 2019). Irrigation projects suffer from time over-runs and cost escalation, and a significant share is abandoned as their completion is no longer economically viable. Recovering the cost of investments has been a long-standing issue (Government of India, 1992). For large irrigation projects undertaken in India, studies found that project costs have increased by as much as 35 times their original costs and many projects remain under construction for up to 35 years but are never completed (SANDRP, 2014). The determinants of these extreme time and cost overruns include, but are not limited to, low quality of appraisal and feasibility studies carried out at the planning and design stage, improper evaluation of project implementation capacity, use of inappropriate technologies and overall cost-ineffectiveness of programs' design, often driven by the political willingness to develop irrigation at any cost (Jain et al., 2019; Palazzo et al., 2019; Ringler, 2021).

Many of the irrigation investments carried out in the 20th century in India included the construction of large dams (Shah et al., 2021). The Central Water Commission reports that over 5000 large dams are currently in operation in India, but many of them date back to last century investment projects and are now over 25 years old (Bathla et al., 2019). Their proper operations and maintenance are neglected, and leakages persist. Moreover, recurrent dam failures pose safety risks such as floods and the loss of lives. In fact, evenduring and shortly after their construction, the Indian dams were already a controversial undertaking in terms of their estimated benefits for agricultural productivity vis-à-vis the negative impacts in terms of people's displacement and environmental degradation (Schulz & Adams, 2019; Duflo & Pande, 2007).

The persistent issue of inefficient water supply and conveyance infrastructure stems beyond aging and arguably unavailing dams to all other irrigation structures, including canals. Inadequate construction and maintenance of canals results in significant water losses due to runoff and seepage (Chauhan & Ram, 2022). Some scholars suggest that liningcanals witha leak-proof layercould reduce water loss by 22.5% (Arshad et al., 2009). Even more importantly, poorly maintained canals often have breaches, which cause the displacement of thousands of people, the destruction of properties and land, and the damaging of costly crops worth millions of Rupees (Jain et al., 2021a). In addition to that, canal breach failures may also cause water shortages, in case the failure occurs during the peak demand period.

The neglect of dams, canals, and other irrigation structures is commonly attributed to insufficient funds generated from water, largely due to its low price (Shah, 2019). To this extent, water audit and budgeting, as well as the establishment of appropriate water prices have all been proven to enhance irrigation efficiency and mitigate water conveyance losses (Hatch et al., 2022). Another reason for delayed maintenance is the absence of control and monitoring structures. Potential solutions include canal automation, volumetric management of water supply, and precise benchmarking of irrigation systems (Rath & Swain, 2020).

The improper management of water and irrigation infrastructure in the country results in overall water use inefficiency, particularly in the low rate of utilization of the ample irrigation potential created. Only 93 Mha of the existing 112 Mha irrigation potential is actually utilized (Vohra and Franklin, 2020). Overall, the average irrigation efficiency was estimated at 38%, which is far below the desired efficiency. Average conveyance efficiency is 70%, and on-farm application efficiency is only 50%.

There is a lot of spatial heterogeneity concerning the various types of irrigation water supply that are relied on (Saleth and Amarasinghe, 2010). Well irrigation is widespread in alluvial plains of the country with sufficient groundwater endowment? This is the case for in Uttar Pradesh, Bihar, Gujarat, Karnataka, and Tamil Nadu, excluding the deserts in Rajasthan. Wells and tube wells provide the benefits of low cost, reliability in drier periods, and independence from large-scale irrigation networks, which makes this irrigation method predominant in India, accounting for two-thirds of net irrigated area (Suresh et al., 2018). However, at the current rate of groundwater depletion in most regions, well failures are becoming increasingly common, making this irrigation method impracticable (Hora et al., 2019).

Canals represent the second most widely used source of irrigation in the country (Shivaswamy et al., 2021). Canals in India mostly irrigate lands with large plains, fertile soils, and perennial rivers, such as the plains in North India, coastal lowlands, and some parts of Peninsular India. In terms of the states, canal-irrigated areas are most prominent in Andhra Pradesh, Assam, Haryana, Jammu & Kashmir, West Bengal, Punjab Rajasthan, Bihar, Karnataka, Tamil Nadu, and Uttar Pradesh.

Finally, tank irrigation is more common in the rocky plateau areas of India that struggle with uneven and highly seasonal rainfall and therefore can hardly be equipped with wells or canals (Jain et al., 2019). The Eastern Madhya Pradesh, Chhattisgarh, Orissa, Interiors of Tamil Nadu, and some parts of Andhra Pradesh have more land under tank irrigation. The use of tanks – irrigation reservoirs in the form of small, mostly natural, lakes or pools – allows for retaining monsoon rainwater. However, this irrigation method has also experienced persistent negative dynamics in the last decade, due to erratic rainfalls and tanks mismanagement (Kumara & Kumar, 2019).

Regarding the methods of water distribution to croplands, the primary technique employed in India is flood, or furrow, irrigation – one of the world's oldest and most water-intensive techniques, where farmers flow water down small trenches running through their crops (Barik et al., 2017). With flood irrigation, water loss through field runoff and evaporation is a major issue (Kumar, 2018). In general, this and other widely applied traditional methods of irrigation have low irrigation efficiency due to excessive seepage loss, as well as inequitable and untimely water supply (Ibragimov et al., 2007; Water Science School, 2018). To mitigate these inefficiencies associated with conventional irrigation methods, modern techniques such as micro-irrigation are commonly suggested as a viable alternative and will be discussed below.

5.3 Status of micro-irrigation in India

The adoption of micro-irrigation techniques has long been recognized as a vital component in improving water productivity and ultimately achieving higher yields (Harsh, 2017; Kumar and Palanisami, 2010; Ali &. Talukder, 2008). Micro-irrigation entails precise application of water on the root zone of plants at low pressure (U.S. EPA, 2022). It relies on small devices that spray, sprinkle, or drip water – hence the main micro-irrigation systems are referred to as spray, sprinkler, and drip irrigation respectively (Madramootoo & Morrison, 2013).

Recognizing the potential benefits of micro-irrigation, the Government of India placed an emphasis on its development in 1992 and 2006 (Centrally Sponsored Schemes on Micro-Irrigation), 2010 (National Mission on Micro-Irrigation), and 2014 (National Mission for Sustainable Agriculture). As mentioned before, to subsume all irrigation-related initiatives, the PMKSY program was formulated in 2015, which considers micro-irrigation as a central component. All programs and schemes under the PMKSY umbrella were targeted at improving water use efficiency and water productivity.

Many scholars have highlighted the potential of micro-irrigation to improve agricultural productivity and water use efficiency in India. The comparative analysis of crop cultivation equipped with drip and flood irrigation systems has confirmed that the former can have considerable positive impact on resource savings, cost of cultivation, crops yield, and farms' profitability (Hatch et al., 2022; Meshram et al., 2019). The physical productivity of water and energy resources has been found to be much higher in drip irrigation than in flood irrigation (Rahimi pool et al., 2022; Umair et al., 2019).

In 2014, the National Mission on Micro-Irrigation (NMMI) surveyed 6000 beneficiaries across several Indian states and presented the Government of India with an impact assessment of micro-irrigation effectiveness (NMMI, 2014). Their findings indicate a 42% gain in farmers' income, as well as considerable savings in irrigation costs, fertilizer costs, and farms' energy consumption (Figure 22). Furthermore, the productivity of growing fruits and vegetables increased by 40-50%.

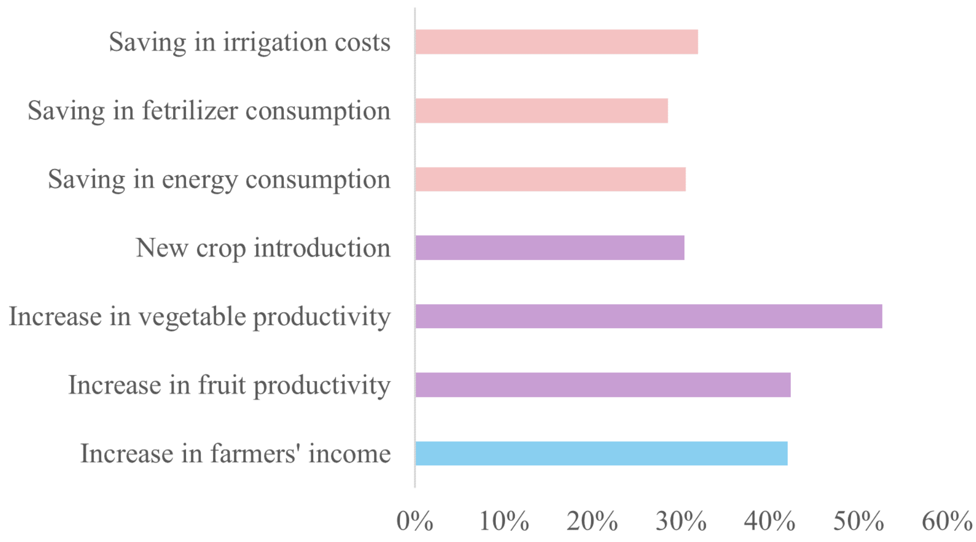


Figure 22: Irrigation coverage in 2016
Source: Constructed by the authors based on data from the National Mission on Micro-Irrigation, 2014.

Nonetheless, despite numerous public initiatives and schemes, the present state of micro-irrigation (MI) in the country is disheartening. The total area equipped with micro-irrigation technologies is 10.3 million ha, while the total estimated potential reaches 69.5 million ha, meaning that India has only realized 14.8% of its micro-irrigation potential (Suresh et al., 2018). Looking at state-wise implementation from 2008 to 2018, Rajasthan – the state with the second most overexploited groundwater resources – led with 18% of country's total area equipped with micro-irrigation (Figure 23). It is followed by Andhra Pradesh (16%) and Maharashtra, accounting for 15%. Specifically, Andhra Pradesh has a leading position in terms of drip irrigation adoption, with a share of 24%, while Rajasthan is a leader in the use of sprinklers (29%). In contrast, Punjab – which is suffering the most with depletion of groundwater resources – accounts for less than 1% of India's total area equipped with micro-irrigation. Haryana and Tamil Nadu – two other states with highly overexploited water resources – have a slightly higher percentage of total area equipped with micro-irrigation, standing at 6% and 5% respectively.

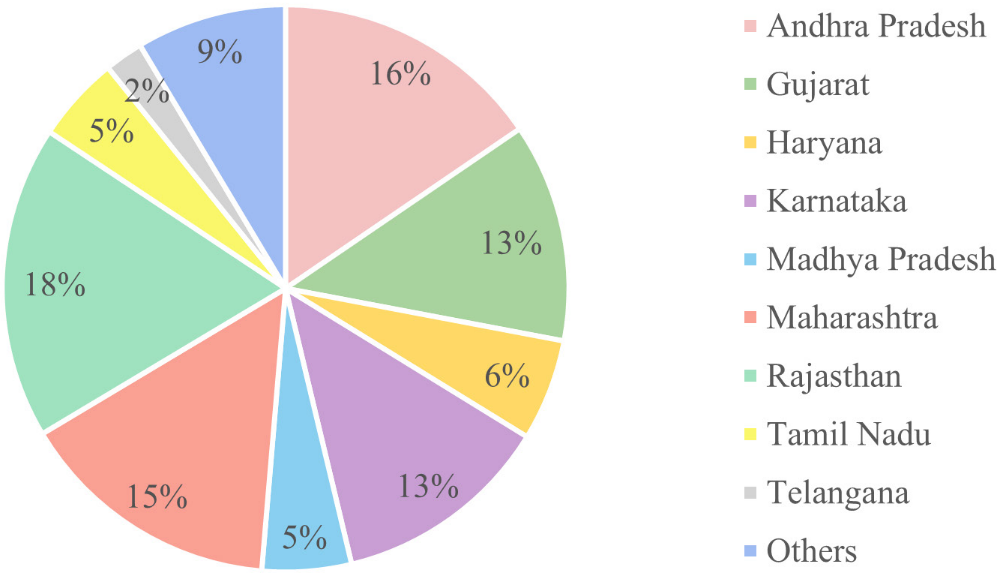


Figure 23: Distribution of micro-irrigation by state in India, 2008-2018
Source: Constructed by the authors based on data from the Government of India, 2021.

Despite the obvious and widely recognized benefits of micro-irrigation and other water-saving technologies, their large-scale adoption is hindered by numerous factors, including farmers' lack of knowledge about the technical and economic feasibility of micro-irrigation, the persistence of traditional approaches to crops cultivation, and poor linkages among key stakeholders (Rao and Anitha, 2021; Bahinipati and Viswanathan, 2019). However, the most important impediment to the widespread adoption of micro-irrigation comes from the sheer expense of the systems. Namara et al. (2005) demonstrate in their case study on Maharashtra and Gujarat that the largest share of micro-irrigation adopters are relatively wealthy farmers. For the poorer tier of the farming population, making use of sophisticated micro-irrigation technologies is not financially viable due to income constraints, and the fact that public assistance programs do not provide funds for re-procurement of micro-irrigation systems that become obsolete before the scheduled disbursement of the next assistance (Namara et al., 2007).

In conclusion, despite concerted efforts towards its development, micro-irrigation, to fulfil its main purpose of water conservation, requires a specialized solution for chronically water stressed areas, where existing schemes have been ineffective (Nair and Thomas, 2022). Studying and adopting best practices from other countries and India's own experience of micro-irrigation development can help national and local governments redesign their water governance structures and present the policymakers with irrigation performance indicators for data-driven decision-making.

5.4 Water and irrigation governance in Tajikistan

The land reclamation and irrigation sector are recognized as primary contributors to the progress towards food security, employment of the rural population, and overall economic development of the country's agro-industrial complex (NPD Steering Committee, 2016). Presently, the management of water resources in Tajikistan is transitioning from a centralized administrative approach that dominated for over three decades to an integrated river basin approach, often referred to as hydrographical or watershed management (Singh et al., 2022; Li & Liu, 2021). In terms of institutional structure, water and irrigation management has mostly been transferred to local communities by creating water users' associations (hereafter WUAs) that were initially established between 2011 and 2013, with ongoing formation. Members of WUAs are drawn from small private farms – dehkans– and receive training in water governance, as well as agricultural extension services (IWMI, 2018; FAO, 2016).

The prime objective for the establishment of WUAs was to enable decentralized and participatory management of water (Buisson and Balasubramanya, 2019; Gunchinmaa and Yakubov, 2010; Dushanbe Water Process, 2022). Their key functions include operating local water infrastructure, implementing irrigation schedules to supply water to farms, repairing and maintaining irrigation canals, collecting fees, and resolving water-related conflicts (Sehring, 2009; ADB, 2013a). Research shows that the establishment and training of WUAs not only improved the condition of irrigation infrastructure, but also incentivized the diversification of crops cultivated by dehkan farms (Figure 24). In 2016, as compared to 2014, farmers allocated less agricultural land to water-intensive cotton and started cultivating more crops with lower water requirement, increasing their resilience to water supply fluctuations. Economically, in the initial years following the establishment of WUAs and the provision of training to their participants, the improvements in water use efficiency enabled farmers to double their incomes and benefited over 200,000 people (USAID, 2017).

Both initiatives – hydrographic management and WUA creation – are part of the fundamental reform strategy focused on establishing integrated water resources management (IWRM). It aims to address the existing challenges faced by the country's land reclamation and irrigation sector, with regard to water distribution, as well as the operation and maintenance of on-farm irrigation systems (Sharofiddinov et al., 2022). The structure of this sector in Tajikistan (Figure 25) is quite unique, since both participatory irrigation management and a hydrographic approach are relatively novel in the Global South. Most countries – including India – still rely on large-scale, centralized water management schemes, and in this sense, Tajikistan acts as a role model.

While the reforms described above are an important advancement towards IWRM, there is still a lot to be done. Water-use efficiency in Tajikistan remains at an extremely low level of 27-46% (Pfefferle et al., 2020). Some of the most pressing issues are the absence of reliable information on water resources and outdated monitoring systems, which result in poor understanding of water systems' behavior (Aliyev, 2021; Nekbakhtshoeva & Babub, 2022). Another major problem is the distribution of water among users because of increasingly unstable supply and growing demand (Husniddin et al., 2022; Opp et al., 2019).

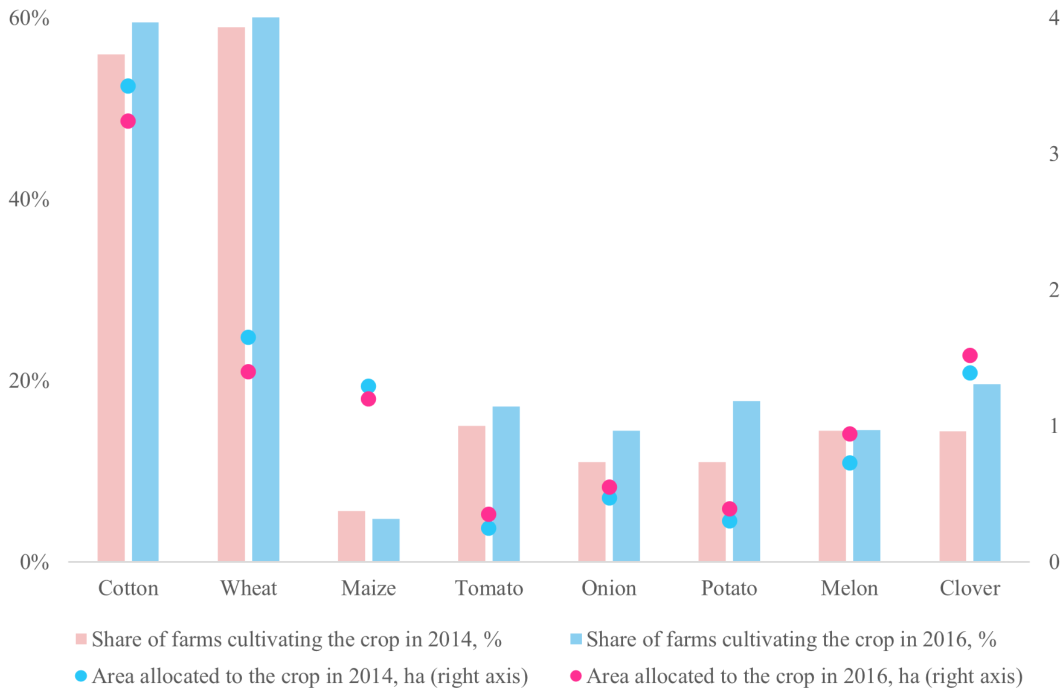


Figure 24: Diversification of cropping patterns by trained WUAs
Source: Constructed by the authors based on data from IWMI, 2018.

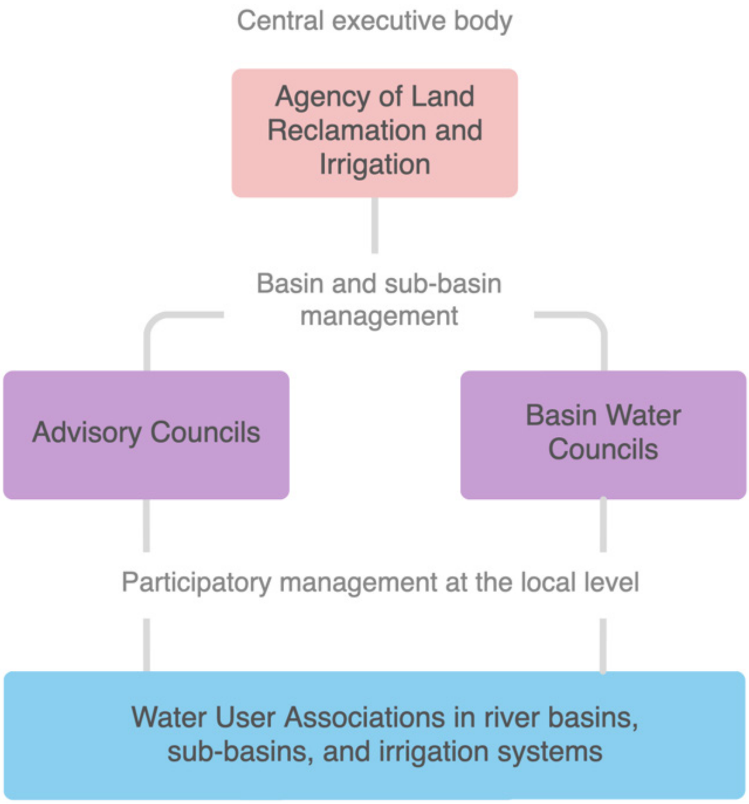


Figure 25: Institutional structure of the land reclamation and irrigation sector
Source: Constructed by the authors based on data from NPD Steering Committee, 2016.

Moreover, existing WUAs lack efficiency, in terms of their approach to users' financial accountability and their role in planning schedules and quantities of irrigation water delivery (Babu & Akramov, 2022; Xenarios et al., 2019; World Bank, 2020b; UNFCCC, 2014). Deficiencies in the structure of water supply payments result in growing debts and irrigation system managers' inability to finance planned infrastructure improvements, which partially explains the low efficiency in the use of water and land equipped for irrigation (Figure 26).

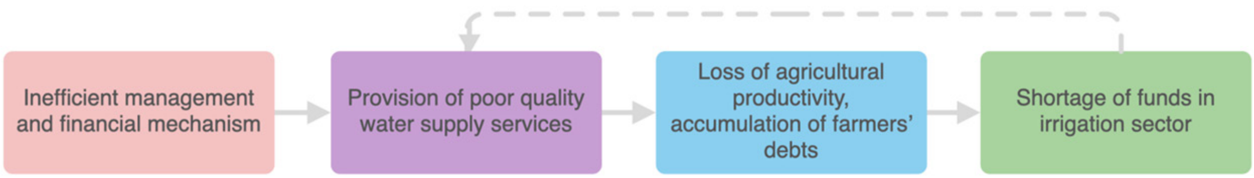


Figure 26: Cycle of unsustainability of land reclamation and irrigation sector
Source: Constructed by the authors based on data from NPD Steering Committee, 2016.

Importantly, incorporating local water users into the water and irrigation governance structures constitutes just one dimension of IWRM. Another crucial aspect involves the establishment of supranational water governance mechanisms, especially in regions like Central Asia where most water basins span across several countries (de Stefano et al., 2010; Duzdaban, 2021). The absence of such structures can lead to conflicts – sometimes even wars – over the water resources. Shortly after the dissolution of the Soviet Union, its former Central Asian republics jointly created the Interstate Commission for Water Coordination to oversee water policy-related issues (ICWC, 2020). However, the Comission has been only partially effective, as the member states – Tajikistan being one of them – still repeatedly engage in water-related conflicts (Wang et al., 2021). In 2008, the country entered an open conflict with Kyrgyzstan over transboundary water resources, resulting in several Tajik districts being completely deprived of irrigation water for more than a week during the vegetation season, which is crucial for the harvest (Peña-Ramos et al., 2021). Apart from such tensions over water, lack of supranational cooperation on water governance leads to a broader range of issues, mainly the inefficiencies in distribution of water across countries and persistence of unsustainable water management practices (Wang et al., 2021; Mallaev, 2021).

5.5 Status of irrigation in Tajikistan

The geographic and climate conditions of Tajikistan make irrigation a vital component of its agricultural productivity. Over 90% of the country's crop production comes from irrigated land, which is very substantial, considering that only about 70% of the total arable land is equipped for irrigation (NPD Steering Committee, 2016). Irrigation coverage varies considerably across regions, depending on how difficult the terrain is for building and maintaining irrigation and drainage infrastructure, and the region's capacity to finance irrigation modernization projects (Figure 27). Moreover, existing irrigation infrastructure is used at highly variable rates as many systems in place fall into disrepair due to poor maintenance or natural disasters (Figure 28) (Burieva et al., 2022; Skakova & Livny, 2020).

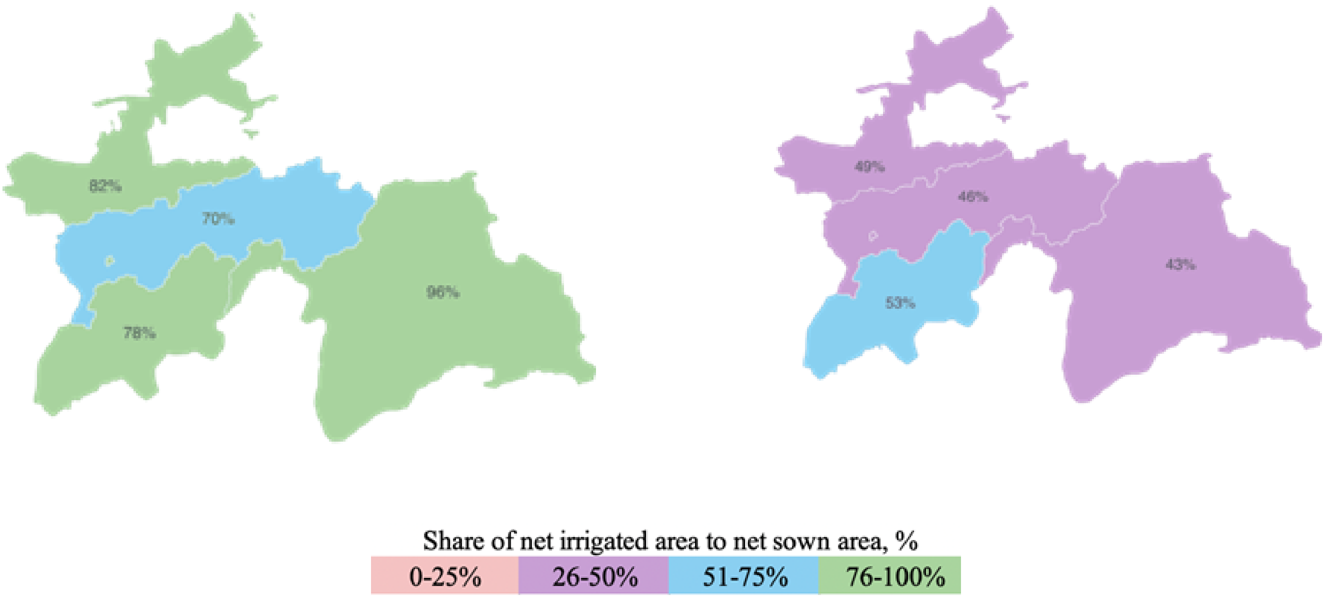


Figure 27: Share of arable land equipped for irrigation by region in 2016, %
Source: Constructed by the authors based on data from the World Bank, 2017

Figure 28: Share of arable land irrigated by region in 2016, %
Source: Constructed by the authors based on data from the World Bank, 2017

The primary method of irrigating agricultural crops in Tajikistan is furrow, or surface, irrigation, accounting for 98% of total irrigated area. This method, a subtype of flood irrigation employed in India, uses furrows – vertical channels – that deliver water to plants' roots (Spencer et al., 2019). Tajikistan is making very slow progress in transitioning from this traditional irrigation method to modern water-saving technologies (Karimov et al., 2022). Only a negligible area (about 100 hectares) is irrigated through drip irrigation (Khakimov, 2019). While the adoption of drip irrigation and other micro-irrigation technologies is difficult due to the financial constraints faced by WUAs, at the state level introduction of these technologies should be given a priority, given the efficiency gains and environmental benefits they can provide (ADB, 2021).

Another source of irrigation inefficiency in the country is that about half of the total irrigated land is equipped with pumping stations, most of which date back to the 1950s-1980s and use energy excessively due to being extremely outdated and worn out (UNFCCC, 2014). Drainage infrastructure is largely outdated as well, leading to salinization and waterlogging of agricultural land (NPD Steering Committee, 2016; ADB, 2013c). The poor state of the irrigation and drainage infrastructure is further deteriorating due to insufficient funding and lack of adequate regulatory measures for its operation and maintenance, resulting from breaches in cooperation among ALRI branches, water suppliers, and water users.

The extent of irrigation inefficiency in Tajikistan is such that, in 2011, one hectare of irrigated land generated income of about US$95. The cost of pumped irrigation for this hectare could reach US$121 if one accounts for electricity subsidies as real costs to the national budget, or US$72 without considering these costs (World Bank, 2017). Overall, pump irrigation is very costly for Tajikistan, both for the responsible agency ALRI and for the energy sector (Figure 29). Moreover, inefficiencies embedded in the irrigation system are extremely costly for the Government of Tajikistan, as it resorts to discounting power tariffs for pump irrigation and cancels large amounts of water user debts (World Bank, 2017).

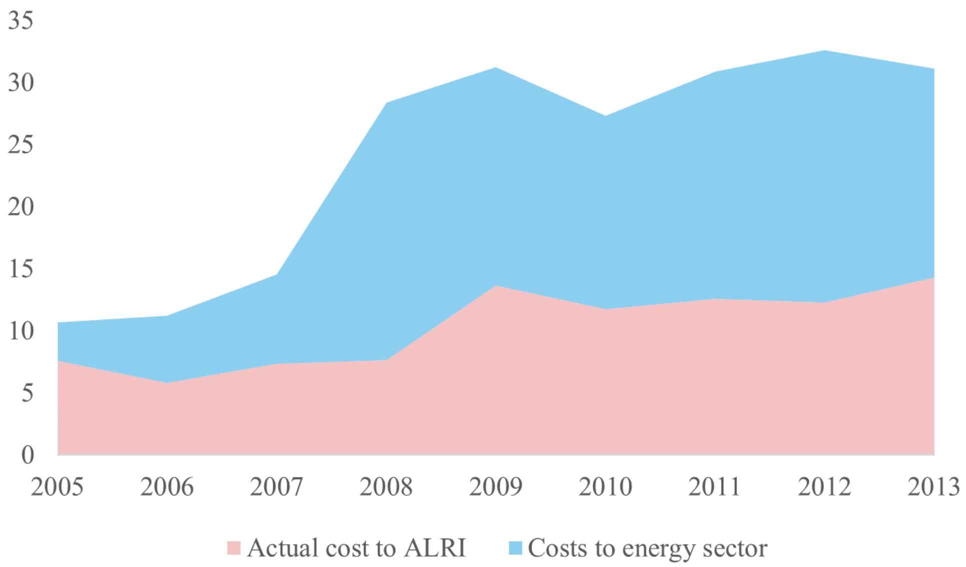


Figure 29: Cost of pumped irrigation to the economy of Tajikistan, 2005-2013
Source: Constructed by the authors based on data from the World Bank, 2017

As explained in the previous subsection, the inefficient performance of water and irrigation agencies is largely responsible for the escalation of irrigation costs. As such, the improvement of irrigation water delivery services is a crucial step that must be undertaken in order to achieve a better cost-benefit ratio in the irrigation sector. Furthermore, it would allow for the creation of a financially sustainable framework where WUAs would actually be able to afford rehabilitation of the outdated irrigation and drainage infrastructure.

5.6 Sustainability of irrigation and cropping patterns in India and Tajikistan

One crucial aspect of maintaining water balance is to consider the availability of water when planning crop cultivation, both at the national and regional level. The rationale here is that crops can have markedly distinct water requirements, leading to different irrigation demands. Regions with a dryer climate and lower water availability could face extreme water stress if they become highly economically dependent on the cultivation of water-intensive crops. As such, it is important to analyze how cropping and irrigation patterns in India and Tajikistan correspond to climatic conditions and water availability at a regional level.

The regional distribution of India's water resources is extremely heterogeneous (Bhanja and Mukherjee, 2019). The increasing demands on water resources by India's burgeoning population, coupled with the diminishing quality of existing water resources have led to a situation where the consumption of water is rapidly increasing while the supply of fresh water remains relatively constant. This dynamic has given rise to severe water deficiencies in states with low initial water endowment.

Examining the map of irrigation coverage in India (Figure 18) alongside the map of climate zones (Figure 8), there is limited correspondence between the inter-regional variation of irrigation patterns and climatic conditions. On the one hand, the driest arid and semi-arid states – such as Rajasthan and Gujarat – have a relatively high level of irrigation coverage (59% and 70% respectively), which is intuitive: agriculture in a dry climate with an unreliable rainfall water supply requires irrigation to secure the harvest. On the other hand, India's most irrigated states – Bihar, Uttar Pradesh, Punjab and Haryana – are all located in the humid subtropical zone, where agricultural productivity suffers much less from rainfall deficiency than in arid areas. Importantly, similar contradictory evidence emerged when analyzing states' irrigation water requirements shown in Figure 19 against their irrigation coverage. Hence, the development of irrigation potential in India seems to be only partially driven by climate-related variation in demand for irrigation across states. This conjecture falls in line with literature that shows how, while irrigation is often developed to compensate for deficient rainfall in hotter and dryer areas, creation of irrigation potential is also largely driven by regions' financial and institutional capacities (Tzanakakis et al., 2020; Kumar et al., 2022).

However, meaningful connections emerge when it comes to the level of irrigation intensity (Figure 18) and groundwater depletion (Figure 9). States with the most critical overexploitation of groundwater resources – Punjab, Rajasthan, Haryana and Gujarat – all belong to the most irrigated regions of India, with irrigation coverage surpassing 70% as of 2017. This outcome results from subsidized electricity for extracting groundwater for irrigation purposes and the expanded production of input-intensive crops (Shivaswamy et al., 2021). Except for Gujarat, these states have all seen a dramatic increase in the level of groundwater depletion since 2004, which is a very alarming dynamic, because groundwater irrigation contributes more than 90% to overall farm livelihoods (Ashok et al., 2021). Other states with highly overexploited groundwater are the southern semi-arid regions of Tamil Nadu and Karnataka, which have less irrigation coverage than northwestern states but still rapidly deplete their groundwater resources during prolonged severe droughts.

When analyzing the structure of India's crop production, one can observe that the most water-intensive crops – rice, wheat and sugarcane – comprise approximately 90% of the country's agricultural production (Barik et al., 2017; Dhawan, 2017). As of 2016, India was the world's second largest producer of these crops, both for domestic and international markets (Ministry of Agriculture & Farmers Welfare, 2019). Growing these crops significantly contributes to the depletion of the country's rapidly declining water resources, for instance, producing one kilogram of rice consumes 3000-3500 liters of water in the agricultural sector (Dhawan, 2017).

Figure 30 brings into focus the extensive cultivation of water-intensive crops across water stressed regions of India. For instance, while Maharashtra is one of the country's most water-stressed states, it is also the largest region with sugarcane cultivation in the tropical area (Harsh, 2017). Similarly, sugarcane and paddy are commonly cultivated in highly water-stressed regions of the Cauvery basin, which spreads over the conflicting states of Karnataka and Tamil Nadu. At the same time, water-abundant eastern states of Odisha, Jharkhand and Chhattisgarh are India's largest producers of spices and plantation crops (coffee, tea, tobacco, etc.) that have relatively low water requirement.

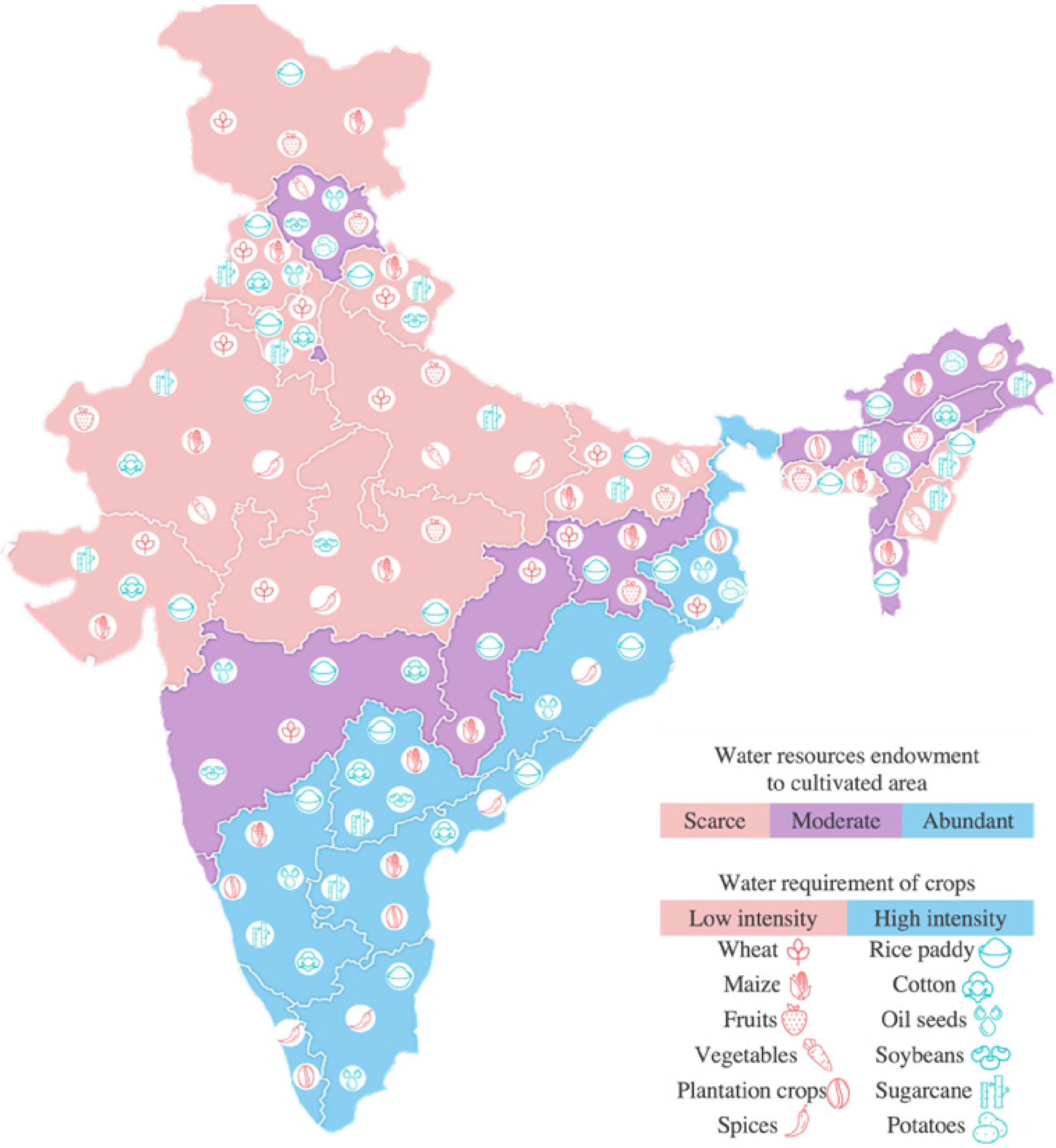


Figure 30: State-wise water resources and cropping patterns in India

Source: Constructed by the authors based on data from Jaganmohan, 2022 (area of water resources by state) and Brouwer & Heibloem, 1986 (crop water needs), Bhatia, 2022, and Vincent, 2022 (state-wise cropping patterns).

The state of Punjab might be India's most striking example of the imbalance between water availability and cropping patterns. In the last decades, driven by "agrarian capitalism" favoring highly marketable crops, the region has gradually shifted from water-efficient varieties like wheat, maize, and vegetables to a rice monoculture that seasonally rotates with wheat cultivation (Singh et al., 2011; Sinha, 2022). Today, the rice-wheat rotation accounts for 80% of the gross cultivated area of Punjab (Jain et al., 2016). To meet the resulting increase in irrigation water needs, the state has largely transitioned from surface water to groundwater for irrigation purposes (Baweja et al., 2017). The heavy reliance of Punjab on groundwater as a source of irrigation for water-intensive rice paddy has led to severe depletion of groundwater beyond naturally replenishable levels, as demonstrated earlier in Figure 9.

The situation in Tajikistan is quite similar to India. Cropping patterns across regions are largely determined by the types of terrain and temperature regimes, rather than the availability of water resources (Figure 31). Extremely water-intensive crops like cotton and rice are predominantly grown in the northern province of Sughd, which is located in the Syrdarya river basin with the highest water stress indicator in the country. The demand for water there already exceeds supply by far (ADB, 2021). The dry desert and semi-arid climate require intensive irrigation, which depletes the flow of the Syrdarya and Amudarya rivers. Additionally, rising temperatures coupled with changing precipitation patterns are likely to exacerbate this process.

At the same time, the Gorno-Badakhshan region, located in the eastern part of Tajikistan in the Pyanj river basin, has the lowest water withdrawal-to-supply ratio and abundant water resources. Despite this, the only crops grown there are vegetables, fruits and wheat, which are all characterized by relatively low water requirements (Khakimov et al., 2020; TAJSTAT, 2018). The only region where cropping patterns are relatively well matched with water supply is the southern province of Khatlon, fed by both the Kafernigan and Vakhsh rivers. This region grows mostly water-intensive crops, yet its high-water endowment allows it to maintain a moderately low level of water stress (ADB, 2021).

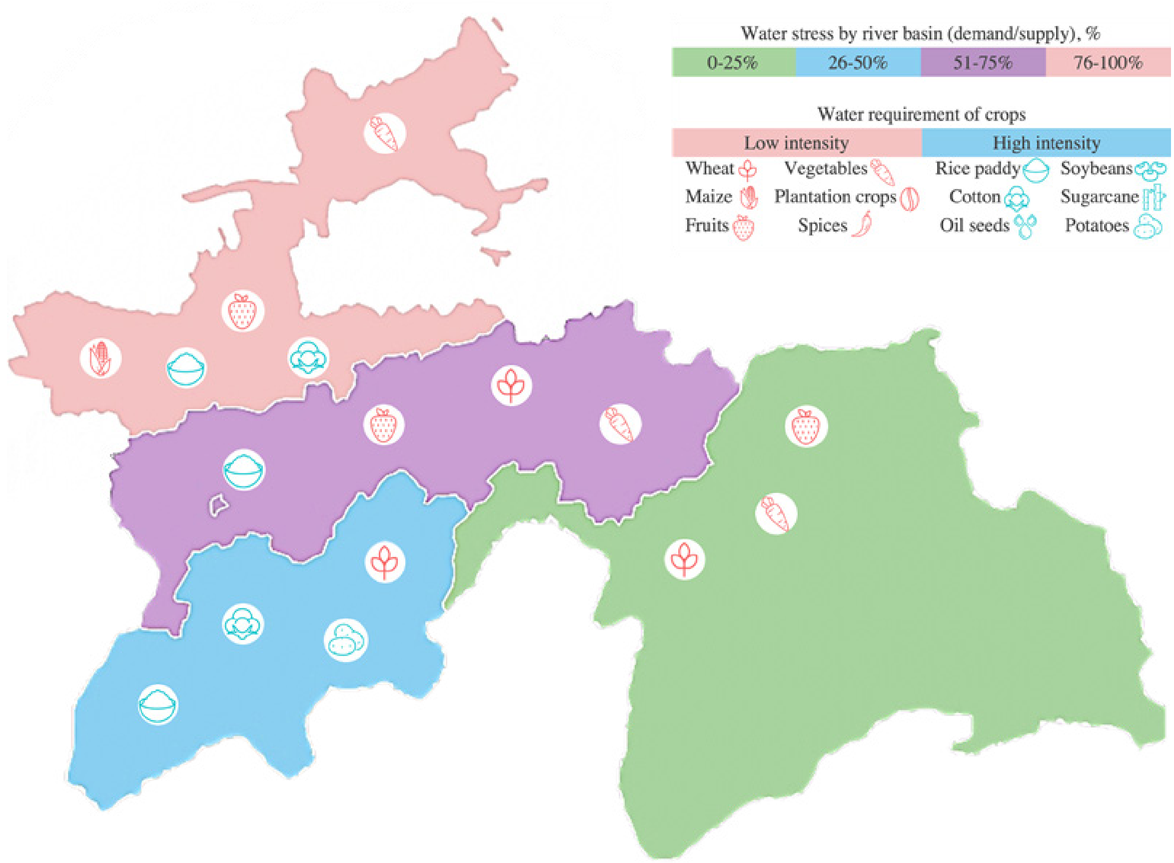


Figure 31: State-wise water resources and cropping patterns in Tajikistan
Source: Constructed by the authors based on the map of Tajikistan river basins by Dushanbe Water Process, 2022; data on cropping patterns by Khakimov et al., 2020, and TAJSTAT, 2018; data on water balances by river basin by ADB, 2021.

By going beyond simply looking at the percentages of cultivated area equipped for irrigation in India and Tajikistan, we were able to observe numerous problems and inefficiencies in the ways these countries manage their water resources and irrigation infrastructure. Building upon the evidence presented in the previous section, we can expect that both relatively water-scarce

India and water-abundant Tajikistan will become increasingly prone to climate change-induced fluctuations in water supply, up to extreme water stress in some regions. Therefore, rethinking the existing irrigation and water management strategies is necessary in the face of groundwater overexploitation, to support the livelihoods of the farming population and mitigate environmental migration, as discussed in the next section.

6. Climate Change and Migration

Given the significant portions of their population reliant on agriculture, mismanagement in the sector and its exposure to climate-related hazards in both India and Tajikistan are likely to have serious implications for many people. The lack of adequate protection by national and local governments creates a situation where some people must resort to migration to protect their livelihoods, which is especially evident in the most drought- and flood-prone areas (Blondin, 2019; Sedova & Kalkuhl, 2020). The combination of extreme climate vulnerability of both India and Tajikistan with insufficient efforts for mitigating its effects on people's lives and incomes made these countries prominent environmental migration hotspots (WFP, 2017; Lukyanets et al., 2020). However, in the academic literature, the evidence on climate-induced migration is relatively scarce, largely because there is a lack a proper record-keeping of climate migrants and the difficulty of disentangling various determinants of migration (Beine & Parsons, 2015). In this section we therefore present the available findings, as well as evidence gathered from reports by various international and local development agencies.

6.1 Protests and migration induced by droughts and water stress in India

Since 2020, India has been experiencing a wave of protests, with thousands of farmers demanding the repeal of market-friendly farm laws (BBC, 2021). While the most direct trigger of farmers' anger is a deep distrust of government reforms, another driver is their longstanding dissatisfaction with the declining profitability of farming and its future as a respectable livelihood.

One outcome of India's current farm policies is the depletion of groundwater as discussed earlier. Government-guaranteed prices for wheat and rice, coupled with subsidized electricity for groundwater pumping have led to over-production in the farming heartlands of Punjab and Haryana (Jain et al., 2021). At the same time, subsidizing the extraction of vast volumes of water for irrigation, and the high energy requirements for pumping that water from ever deeper levels below the ground placed a large burden on state finances as well as the local environment (Sinha et al., 2018). Moreover, pumping – which often involves the use of inefficient diesel pumps – contributed to increasing greenhouse gas emissions from agriculture that counteract climate change mitigation efforts.

The region from which a large part of the protestors originates – the fertile land in north-western India known as the 'breadbasket' of South Asia – has been identified as a water-stressed climate change hotspot (Siderius et al., 2021). Farmers in the region and across the country need support to move away from producing an excess of heavily subsidized, water-intensive crops such as wheat, paddy rice and sugarcane, in order to relieve water stress and achieve a sustainable level of crop production that would secure their incomes from farming in the long run (Husenov et al., 2020).

Currently, Indian farmers face numerous economic and environmental challenges. According to a survey of farmers across 18 Indian states conducted by the Center for the Study of Developing Societies (CSDS), when asked about their biggest problem, the most common responses included floods and droughts, lack of access to irrigation, declining productivity and incomes (Figure 32). With respect to the latter, while 79% of respondents indicated to depend on farming as their primary source of income; however, 62% of them said they would quit farming for a respectable job in the city (CSDS, 2018).

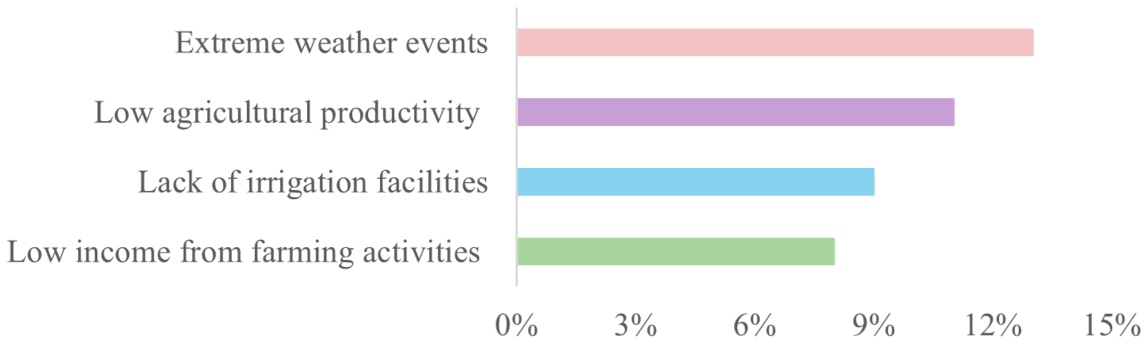


Figure 32: Prevalence of various challenges faced by farmers in India, %
Source: Constructed by the authors based on data from CSDS, 2018.

Due to the unsatisfactory conditions of Indian farmers, exacerbated by increased occurences of drought and water stress, researchers are pointing out an increase in migration aspirations and actual migration – both internal and international (Maharjan et al., 2018; Cundill et al., 2021; Banerjee, 2015). A World Bank report indicated that the southern highlands between Bengaluru and Chennai would soon become some of the world's major hotspots for internal migration (World Bank, 2018). In Bengaluru – the capital of Karnataka state – most migrants come from the north rural areas of the state, which have been grappling with prolonged droughts. In these drought-prone areas, farming as an occupation is disappearing due to the dwindling water resources, compelling people to migrate to urban areas in search of alternative employment opportunities (Gogoi and Tripathi, 2019).

In the report published by NITI Aayog, it was estimated that 600 million Indians, or almost half of the country's population, already suffer from high to extreme water stress (NITI Aayog, 2018). It was projected that by 2030, 40% of the Indian population will no longer have access to drinking water. Droughts can also disrupt electricity generation from hydropower, and in India, 17% of the total electricity supply comes from hydropower (Tiwari & Mishra, 2019). Moreover, water shortages during drought periods create a favorable environment for the spread of diseases and higher concentrations of pollutants, both of which can have extremely harmful consequences for people's health (Moors et al., 2013; Sorensen et al., 2018). Research also points out that, as extreme heat periods reduce crop yields and inflict economic hardship on Indian population, in the last three decades the warming temperature trends have been responsible for over 59,000 suicides throughout the country (Carleton, 2017).

Thus, for populations in areas subject to the most severe water scarcity and climate extremes, these environmental factors are gaining importance as triggers for migration. For instance, in the Bundelkhand region comprised by the states of Uttar Pradesh and Madhya Pradesh, the critical levels of water scarcity resulted in heavy outward migration in search of water and better livelihood opportunities (NITI Aayog, 2018). In recent years, some districts and villages in the region managed to partially solve the issue of out-migration by creating rainwater collection and storage capacities and restoring water bodies (Yachna & Rakesh, 2017). In the state of Bihar, one of India's highest contributors to out-migration, a survey of 700 households revealed that two-thirds of respondents considered migration as their adaptation strategy of choice in the face of rapid and slow-onset climate hazards; importantly, the survey focused on migration aspirations, rather than actual migration decisions (Jha et al., 2018).

It is important to note, however, that sudden or progressive negative changes in the environment are rarely identified as the primary reason for migration (Cundill et al., 2021). Rather, environmental factors typically act as a “threat multiplier” exacerbating pre-existing socio-economic insecurity and thus indirectly influencing people's migration decisions (Singh, 2019; Singh et al., 2019). In a survey of 5479 households across various locations in India, Ghana and Bangladesh, only 3% of respondents stated environmental threats as the main determinant of their decisions to migrate (Safra de Campos et al., 2020). However, up to 80% of them acknowlegded the contribution of environmental stressors to the overall insecurity of their livelihoods. Regarding displacement, however, climate hazards are a major concern; according to the Internal Displacement Monitoring Centre, 53.4 million internal displacements took place in India in 2008-2021 due to natural disasters (IDMC, 2022). Therefore, although the deteriorating environment is most often not the main push factor, it is still an important driving force behind migration and displacement of the Indian population, especially of people with the least economic and social security (Sarkar et al., 2022; Kumar & Viswanathan, 2012).

6.2 Climate change-induced migration in Tajikistan

Since becoming an independent state in 1991, Tajikistan has consistently experienced net outflows of its citizens, evolving into the largest regional labor exporter (Erlich, 2006). In the period before and during the global financial crisis of 2008, the country had the highest rates of average annual net migration in Central Asia and the Caucasus region (CAC DRMI, 2009). Since then, international emigration has been steadily slowing down, but still remaining larger than immigration until today (Figure 33). The issue is further exacerbated by the fact that international emigrants are predominantly working-age males who are forced to seek employment abroad (primarily in Russia) due to domestic labor demand shortages and low wages that do not allow them to sustain themselves and their families.

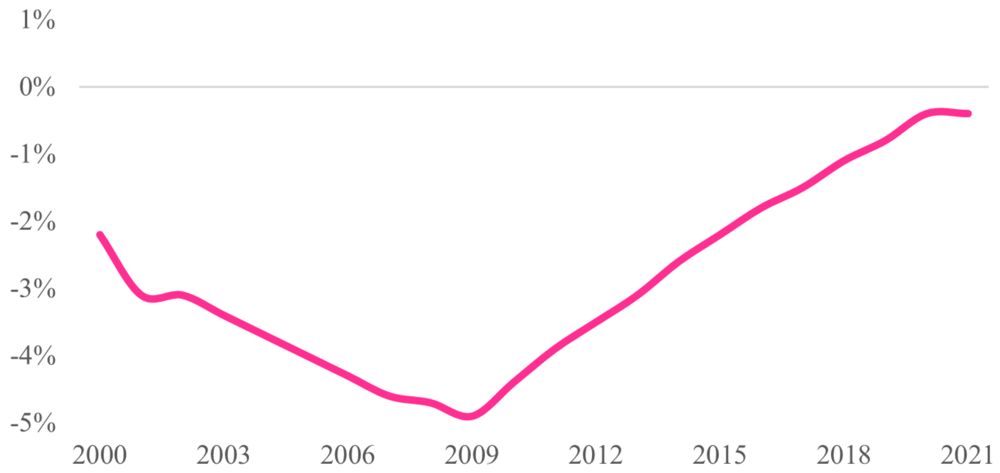


Figure 33: Net migration in Tajikistan, 2000-2021
Source: Constructed by the authors based on data from International Organization for Migration, 2022.

The primary driver behind the mass exodus of the Tajik population is the inability to scure employment in their home country that earns a decent income or supports further education. However, beyond economic factors, there are other non-economic dimensions to this phenomenon, with the most prominent being large-scale environmental degradation, including extreme temperatures, adverse climatic shocks, and reduced precipitation (Blondin, 2020). Not only is Tajikistan highly susceptible to climate-related hazards due to its mountainous landscape, it also has a very low capacity for mitigating these shocks and adapting to their consequences. This lack of emergency management capacities is a result of exposed and insufficiently robust infrastructure (Climate Change Knowledge Portal, 2022; World Bank, 2013). Low disaster preparedness leads to unmitigated destruction of houses and infrastructure, causing mass displacement of people in areas affected by climatic shocks (IOM, 2015, ADB, 2013b).

The agricultural sector bears the brunt of climate change, due to the high sensitivity of workers' incomes and various institutional constraints (IOM, 2015; Heltberg et al., 2012). Incomes of workers involved in the agricultural sector are the lowest among all economic sectors and are essentially unprotected from losses in agricultural productivity due to natural hazards (UNFCCC, 2014). The combination of climatic, economic, and institutional factors creates a situation where already low incomes of agricultural workers significantly suffer, thereby accelerating external labor migration (Khakimov and Mahmadbekov, 2009). In recent years, Tajikistan has reached the point of becoming region's most prominent hotspot for environmental emigration (WFP, 2017).

Notwithstanding, scholars have started pointing out another facet of how environmental degradation affects Tajik people's migration aspirations, namely 'involuntary immobility'. They argue that while rapid onset hazards like floods and droughts incentivize migration, more long-term environmental factors, such as the gradual increase in temperature and precipitation from historical averages, are associated with liquidity constraint–related effects and a subsequent reduction in emigration (Murakami, 2020; Blondin, 2020).

The interconnectedness of food security, climate change, and migration is evident in both India and Tajikistan, and the way the two countries manage their water and irrigation sectors plays a crucial role in protecting people's livelihoods amid the worsening climate conditions. Appropriate measures for improving the efficiency of water and irrigation management are discussed in the next section. Failure to implement these – and other – measures will inevitably lead to further intensification of environmental emigration flows of people who pursue more viable living conditions with less water stress, better earning opportunities and access to food, as well as rising involuntary immobility among people who would also wish to migrate but remain trapped in place due to economic constraints (Maharjan et al., 2018; Banerjee, 2015; Blondin, 2019).

7. Ways Forward for Water and Irrigation Management

Despite the wide range of measures undertaken by the governments of India and Tajikistan and the fact that both countries managed to achieve the highest levels of irrigation coverage in the Global South, the overall uptake of water conservation is still poor (Pani et al., 2021; NITI Aayog, 2018; Sodikov et al., 2022). Even in Tajikistan, with abundant water resources and an established participatory irrigation management system, structural deficiencies persist in the land reclamation and irrigation sector. In both countries, such deficiencies are not only costly for the federal budget, but also extremely harmful for their population and environment.

The common approach for countries facing declining agricultural productivity and water stress is to promote the wide-spread adoption of new irrigation and water saving technologies (Fernández García et al., 2020; Evett et al., 2020). However, in low- and lower-middle income countries like Tajikistan and India, affordability of implementation is an important concern, and there is lack of understanding of the extent to which the returns from these undertakings compensate the costs (Grafton et al., 2018).

Therefore, in this paper, after conducting an extensive overview of academic literature, as well as reports and guidelines, by international and local development agencies, we have identified other areas for potential improvement, which include but are not limited to the introduction of more efficient agricultural technologies. Most of the proposed measures are relevant for both India and Tajikistan and can also be useful in other low- and middle-income countries. We would like to emphasize, however, that the approaches listed below are not entirely unheard-of; most of them have already been implemented – and proven effective – in different areas of India and Tajikistan. Thus, our objective is to provide a comprehensive list of measures that may be considered by policymakers when inspecting which approaches can be implemented in their jurisdictions.

7.1 Balancing water supply and demand in India and Tajikistan

In both countries, there is an urgent need to match water supply and demand (OECD, 2016; Jain et al., 2019). Supply-side management practices include watershed development, water resource management through irrigation initiatives of different scale, establishment of reasonable water pricing schemes, and the development of drainage systems and water reservoirs (Vohra and Franklin, 2020; Shah, 2019). Demand-side management practices include enhancing water use efficiency, providing training and agricultural extension services, optimizing cropping plans, and balancing of virtual water trade (Figure 34). Moreover, both countries could benefit from improving the resilience of their infrastructure to natural hazards and implement policies for protecting agricultural workers from climate-related shocks.

Management measures

The allocation of public funds and policy design should shift away from large-scale irrigation initiatives and mass cotton and rice production and towards water conservation measures in both irrigated and rainfed land, as well as community-based hydrographical management programs. Moreover, the Agency of Land Reclamation and Irrigation in Tajikistan and the Ministry of Water Resources, River Development and Ganga Rejuvenation in India would benefit from developing the capacity to collaborate more closely with other governmental agencies (in particular, the Ministry of Emergency Situations), local governments, WUAs and communities (Thatte, 2017; Ahmed & Araral, 2019).

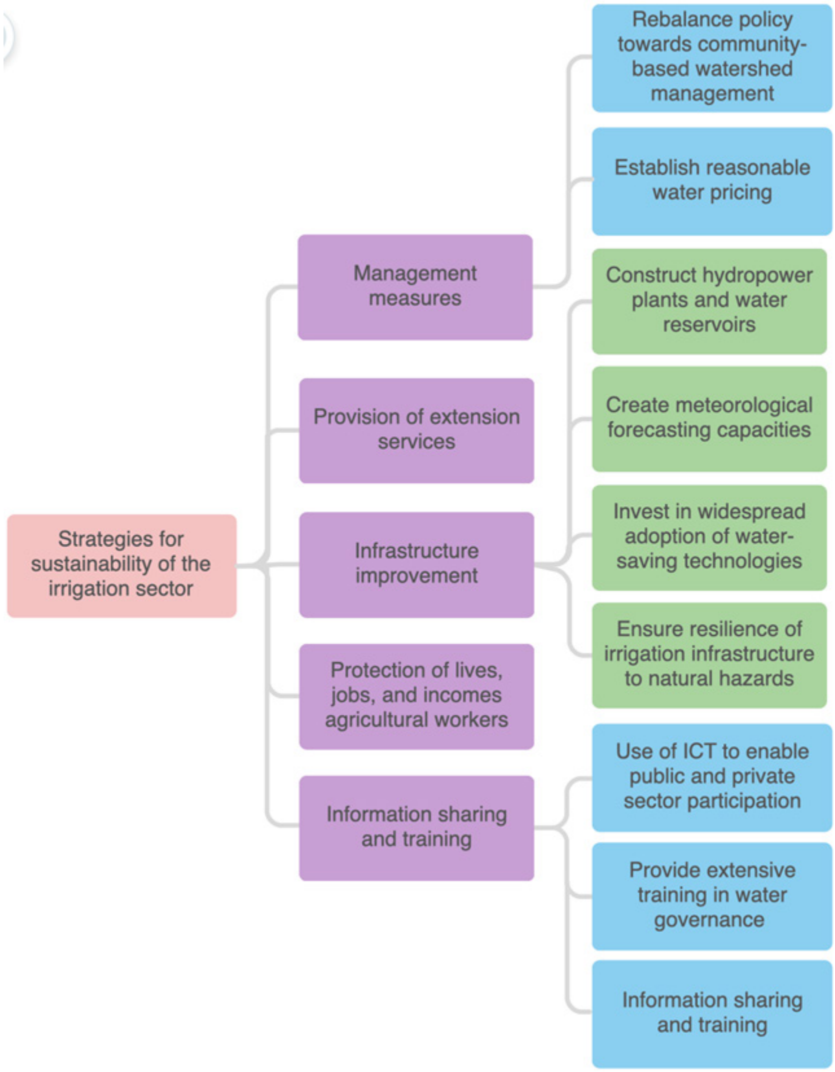


Figure 34: Proposed strategies for improved water and irrigation management
Source: Constructed by the authors.

The establishment of reasonable water pricing – without the distortionary effects of water and energy subsidies – is another crucial component for the implementation of water conservation measures (Sharofiddinov et al., 2022; El Bakia et al., 2018). Adapting to climate change inevitably requires more efficient water usage. Existing water and energy tariffs and fees in the irrigation sectors of both India and Tajikistan are set at a very low, often further discounted levels and fail to cover the costs of water provision, rehabilitation of irrigation and drainage systems (Aliyev, 2021). For instance, in Punjab, where groundwater is extremely overexploited because of heavily subsidized electricity for irrigation water pumping, de-subsidizing could help bring down groundwater extraction to replenishable levels and thereby promote water conservation (Ashok et al., 2021). Furthermore, in Tajikistan, the insufficiency of funds collected through small fees paid by water users is exacerbated by poorly managed fee collection procedures, leading to debt accumulation and creating further losses in agricultural productivity and inefficient use of water resources. Since depleting water resources are becoming insufficient to meet the increasing demand for food, higher water use efficiency in agriculture is becoming an urgent necessity (Kobuliev et al., 2021).

Provision of extension services

The development of agricultural extension services is necessary to promote sustainable land management, as it facilitates diversification towards crops with lower water dependency and increases agricultural productivity (Heltberg et al., 2012). In Tajikistan, improving irrigation delivery services was shown to reduce cultivated areas of cotton in favor of other high value crops, which not only helps with water conservation, but also increases and diversifies farmers' incomes (Buisson and Balasubramanya, 2019). It is especially important for areas like the Sughd province, where extensive cotton and rice cultivation have led to a large mismatch in water supply and demand and, consequently, a high level of water stress. In India, similar results could be achieved, since it is also highly dependent on water-intensive rice production, which could be addressed through extension services (Norton & Alwang, 2020; Khatri-Chhetri et al., 2019; Hayat, 2019).

Infrastructural development for adequate and regular water supply

In both India and Tajikistan, canal water supply in many command areas lacks adequacy and regularity, adversely affecting agricultural productivity and harming farmers' incomes (Sinha et al., 2018). Tackling this issue requires the facilitation of conjunctive water use. Furthermore, appropriate infrastructures should be built to supplement surface and ground water. In particular, the construction of storage reservoirs on rivers and their connection to various states could help offset existing regional imbalances and provide additional irrigation, ensure timely and adequate water supply, and assist in hydropower generation (Dhawan, 2017). The issue of water logging and salinity that many command areas suffer from also calls for conjunctive water use, where both groundwater and surface water resources are used harmoniously (Sabale et al., 2023; Evans et al., 2015; Foster et al., 2010). This strategy was successfully implemented in Odisha as part of a water management program that stored surface water underground during normal and high rainfall periods and then pumped groundwater from storage during drought spells (Rani Sethi et al., 2020;). Moreover, appropriate drainage systems that would ensure the timely removal of excess water from the soil should be designed and installed, along with the implementation of other approaches for the management of salt-affected soils like cultivation of salt tolerant crops (Kumar & Sharma, 2020).

Improving irrigation efficiency

In a discussion about irrigation efficiency, one cannot go without mentioning micro-irrigation technologies such as drip and sprinkler systems. Comparative estimates of effectiveness of various irrigation methods reported in the literature indicate that drip irrigation has the highest application efficiency of 90% and overall efficiency of 80-90% (Figure 35). Sprinkler irrigation performs similarly well in terms of conveyance and application efficiency, but it has substantially lower estimates for surface water moisture evaporation, hence its positive impact on water conservation is significantly lower than for drip irrigation systems.

Other measures that can assist in water conservation include using farm ponds to store water harvested from slopes and gullies or covering the soil with plastic and crop residues to prevent water loss through evaporation (Narayanamoorthy, 2022). Innovative agronomic practices advised for enhancing water productivity include ridge-furrow sowing – i.e., planting crops on ridges above the soil that alternate with furrows, or trenches, for draining excess water, – subsurface irrigation that places water delivery lines below the land surface to avoid evaporation, and precision farming technologies for real-time observation and measurement of crop cultivation (Liu et al., 2020; Mohammed et al., 2021; EIP-AGRI, 2019).

As climate change can lead to a gradual reduction of water resources – both in water-scarce India and currently water-abundant Tajikistan – implementation of micro-irrigation technologies is highly recommended due to their water-saving capacity and potential to increase agricultural productivity that has been demonstrated above. While these technologies have high relative costs, possible solutions include preferential long-term loans where the interest rate can be covered by the country's government or grants (Khakimov, 2019).

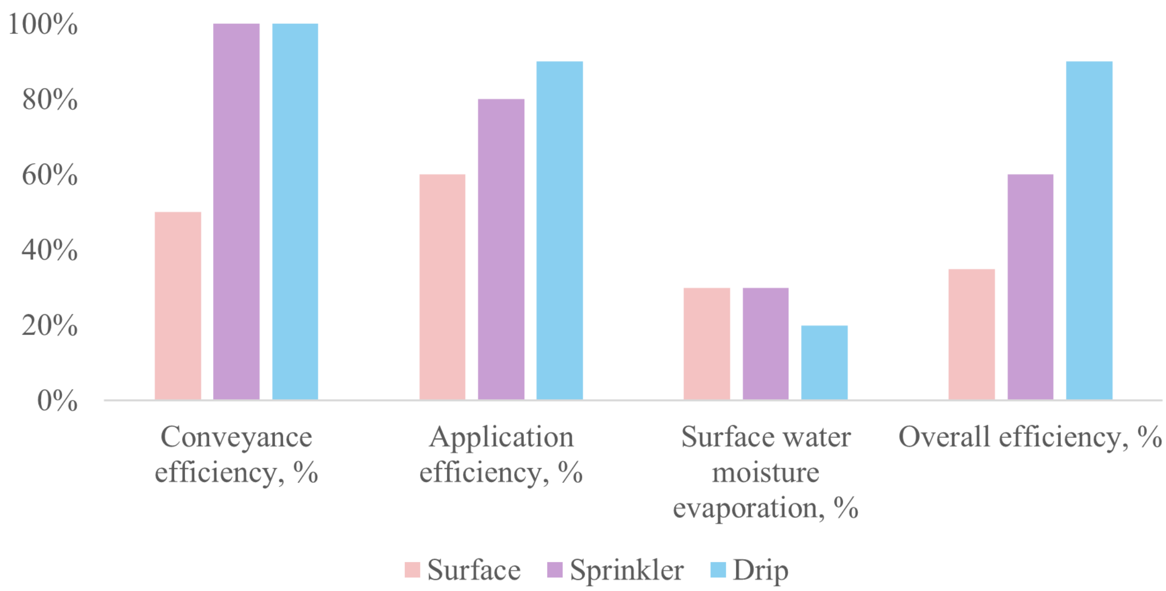


Figure 35: Efficiency of various irrigation technologies
Source: Constructed by the authors based on Saleth and Amarasinghe, 2010; Narayanmoorthy, 2006; Kumar and Palanisami, 2010.

Optimum crop plans

We have pointed out how the state-wise patterns of crop cultivation in India and Tajikistan do not account for regional water availability, which leads to water supply imbalances and depletion of water resources in certain states. To address this issue and considering the varying water requirements of different crops, groundwater exploitation could be reduced by moving production of water-intensive crops to water-abundant states (Jain et al., 2016). For instance, to restrict groundwater extraction to replenishable limits in water-stressed regions, areas where rice, cotton, potatoes, sugarcane, and other water-intensive crops are cultivated could be reduced and instead reallocated towards maize in kharif season and wheat in rabi season. To facilitate this shift, farmers should be incentivized to adopt optimal cropping plans; and compensation for losses in farm income due to adoption of these optimal patterns should be provided, as they moght generate lower revenues under current levels of technology and market prices (Jain et al., 2016).

Virtual water trade

The issue of rampant water-intensive crops cultivation in India and Tajikistan transcends countries' national borders. A comparison of water use statistics shows that farmers in India use 2-4 times more water per unit of grain compared to countries like China or Brazil (Jain et al., 2019). The disparity in the indirect water export-to-import ratios across countries is striking; the ratio is 4 in India and 0.1 in China, thereby making China a net importer of virtual water flows (Dhawan, 2017; Tian et al., 2018; Goswami & Nishad, 2015). That is because, as indicated in the previous section, India exports water-intensive crops like rice, cotton, sugarcane and soybeans, while China exports agricultural commodities with low water requirement, i.e., vegetables, fruits, and processed foods. Similarly, the cultivation of cotton in Tajikistan is almost exclusively export oriented.

Therefore, there is a pressing need to reconsider existing international trade policies to bring the virtual water flow from India and Tajikistan under control. The reduction of indirect water outflows could be achieved via a shift away from water-intensive crops – sugarcane, rice, cotton, etc. – to much less water-intensive but high-value commodities like pulses, fruits, vegetables, legumes, medicinal plants, and others.

Protection of agricultural workers

When implementing institutional reforms, the governments of India and Tajikistan should focus on eliminating constraints that tie farmers to rice and cotton cultivation while ensuring secure land titles (World Bank, 2013). Furthermore, to mitigate labor market imbalances and reduce labor migration and involuntary immobility, the governments can provide temporary public employment opportunities. On the one hand, this approachs safeguards low-income and food-insecure households, including labor migrants returning to the country (World Bank, 2015) while generating the necessary workforce for rehabilitation of outdated irrigation and drainage infrastructure. This measure is still novel in the Global South and has so far been implemented mostly in developed countries like Canada and Australia (Clibborn, 2019; Hennebry & Preibisch, 2012). Further research is needed to determine how such policy can be tailored to low- and lower middle-income countries' context.

7.2 Rethinking Participatory Irrigation Management strategies

Participatory Irrigation Management (PIM) policies draw on the broader ideas of economic liberalization and service privatization along with an emphasis on the decentralization of irrigation management responsibilities to local governments and user-based associations (Chattopadhyay et al., 2022; Shah, 2019). International donors like the World Bank and the United States Agency for International Development (USAID) have promoted these reforms since the 1980s and made the availability of funds conditional to the adoption of the PIM practices.

Strengthening the performance of local level water institutions and water users' associations (WUAs) was shown as a viable way of improving water delivery, increasing crop yield with greater crop diversification, increasing farmers' income, and improving financial sustainability of irrigation systems (Zhang et al., 2013; Sudgen et al., 2020). The study conducted by Ghosh et al. (2019) revealed that implementation of PIM in six Indian states had a beneficial impact on numerous measures of agricultural productivity, as well as on irrigation coverage; however, the use of fertilizers also increased, which can be ambiguous due to their environmental impact (Figure 36).

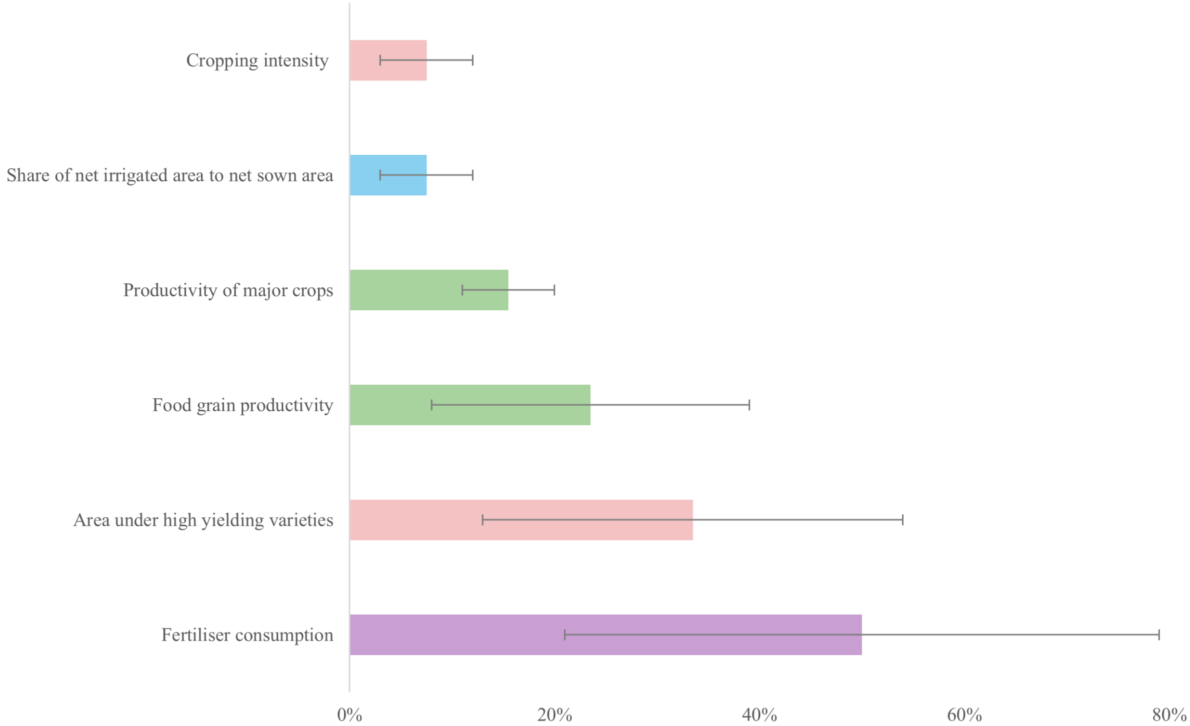


Figure 36: Effects of PIM enactment in six Indian states
Source: Constructed by the authors based on data from Ghosh et al., 2019

While recognizing the benefits of PIM enactment, one must beware of the potential problems that arise from its faulty implementation (Hamada & Samad, 2011). Until today, the performance of WUAs in India and Tajikistan suffers from weak governance. As has been mentioned in Section 4.4, in Tajikistan and in several Indian states, WUAs struggle with low rates of fee collection from water users, due to farmers' lack of awareness or financial capacity to pay, and structural deficiencies in the fee collection system (Gandhi et al., 2020; Shenhav et al., 2017). Also, in both countries, WUAs do not necessarily deliver on the promise of inclusivity, as the involvement of female farmers and the youth is relatively low (Balasubramanya, 2019; Gandhi et al., 2020). Moreover, WUAs in India and Tajikistan still do not receive adequate institutional support and training services for farmers, resulting in low standards of operation and maintenance, which halts the progress that could be achieved through PIM (Ghosh et al., 2019). Many WUAs do not employ staff to carry out the basic functions of water management, maintenance and record keeping, which results in poor service delivery.

Therefore, the Agency of Land Reclamation and Irrigation in Tajikistan and the Ministry of Water Resources, River Development and Ganga Rejuvenation in India could benefit from focusing on providing access to and assistance with the interpretation of information on water availability and weather variability to all stakeholders, including local agricultural producers, extension service providers, WUAs, etc. (IWMI, 2018). The financial viability of WUAs could be improved through clear communication of their functions and benefits to water users, ensuring equity in water allocation and cost sharing among members and introducing effective penalties for free-riders, and improving the overall financial transparency of WUAs budgeting (Hamada & Samad, 2011). Moreover, to increase the effectiveness of the participatory irrigation management system, water users should receive extensive training and knowledge regarding crop diversification, water and energy use efficiency, and potential risk-sharing strategies (Pfefferle et al., 2020). Finally, ICT, including mobile platforms, can be used to create a demand-based model for water delivery and climate information and greater public and private sector collaboration and innovation (WFP, 2018).

7.3 Improving the disaster preparedness of Tajikistan

Due to its unique geographic and climatic conditions, Tajikistan faces an urgent need to improve its resilience to extreme weather events – mainly flooding and droughts, but also avalanches, mudflows, and landslides. Existing infrastructure is extremely vulnerable to such climatic shocks, which results in loss of human lives and people's incomes, especially in the poorest communities.

Given the increasing frequency of extreme climatic events – especially floods – Tajikistan urgently needs to develop early warning systems and improve coordination of disaster response efforts. This involves turning local communities into active participants in emergency prevention and management process (Dazé, 2016; Kull, 2021). Moreover, as a major net provider of water and hydropower to neighboring countries, Tajikistan bears even more responsibility to rebuild the meteorological forecasting capacities, particularly regarding glacial snowmelt and potential flooding (World Bank, 2006; World Bank, 2020a).

Another important avenue for Tajikistan to tackle environmental and food security issues domestically and regionally is to construct hydropower plants and water reservoirs (Mukhabbatov et al., 2020). This initiatieve would help the country and Central Asia to mitigate water shortages in the downstream communities, thereby preventing disruptions in irrigation water supply and resulting losses in agricultural productivity (Amirova et al., 2019). Given that there is a dedicated supranational organization in Central Asia that oversees transboundary water-related matters – the Interstate Commission for Water Coordination – such infrastructural projects could potentially be financed jointly by Tajikistan and neighboring countries (Krasznai, 2019).

The measures proposed in this section were developed with a comprehensive vision of encompassing many different aspects of water and irrigation management. While certain aspects, in particular infrastructural developments, might be costly to realize, careful planning and management can help the responsible agencies to prevent escalation of costs and ensure that long-term benefits cover high upfront investments. As we have demonstrated in the previous sections, lack of immediate action also turns out to be extremely expensive for the governments of India and Tajikistan, as they keep financing highly inefficient water and irrigation systems.

8. Conclusion

Climate change reduces agricultural productivity, thereby threatening food security and reducing earnings of people involved in agriculture. Agricultural workers and people living in rural areas in the Global South tend to be the most vulnerable (Azadi et al., 2021; Bertolini, 2019). Climate-smart agricultural technologies can mitigate negative environmental factors, with irrigation being one of the widely adopted solutions. It has the potential to significantly improve agricultural productivity and ensure a more stable and adequate water supply, as opposed to rain-fed agriculture. However, it does not come without several important caveats. Irrigation infrastructure tends to be extremely expensive to build and challenging to maintain (Palazzo et al., 2019; Ringler, 2021). Furthermore, it must be skillfully managed to prevent overexploitation of water resources and land degradation.

While it is commonplace to look at countries like India and Tajikistan, which managed to equip most of their cultivated lands with irrigation infrastructure, as positive examples for other Global South countries, it is important to look beyond irrigation coverage figures into more nuanced aspects of water and irrigation management. The aspects that merit consideration include, but are not limited to, the quality of infrastructure used for irrigation, drainage and water storage, the extent of water conservation and water use efficiency, the provision of training and agricultural extension services, involvement of stakeholders at various levels in all stages of water and irrigation management, climate-smart optimization of cropping plans, and disaster preparedness.

In this article, we aimed to provide a comprehensive comparative analysis of how India and Tajikistan manage their water and irrigation sectors. Despite consolidated efforts by national, regional, and local governments and international development agencies, agricultural water productivity in both countries remains low, with some regions already facing depletion of their water resources. Climate change further exacerbates the situation, especially in regions with pre-existing socio-economic instability. Resulting food insecurity and loss of incomes, in some cases, leads to forced environmental migration among people who can afford to move and creates trapped populations among those who cannot.

Irrigation development policies and their effectiveness have been assessed at various levels of governance, accounting for regional differences. We demonstrate that in both countries, considerable spatial heterogeneity exists in the extent and quality of irrigation coverage, which seems to persist over time. At the same time, regions within India and Tajikistan have vastly diverse climatic conditions, water, and land endowments, contributing to the variation in irrigation deployment. However, there could be other mechanisms at play. Regions vary greatly in their capacity to invest in creating, operating, and maintaining irrigation infrastructure, in terms of both financial and human capital. When financial and institutional capacity is lacking, irrigation systems in place are constructed and employed in suboptimal ways, resulting in water and energy losses. Moreover, irrigation is most intensively deployed in the regions that cultivate water-intensive crop varieties, which also often happen to be the most water-scarce, therefore depleting water resources and disrupting ecosystems. Furthermore, faced with growing food and water demand, different actors and stakeholders increasingly compete for these dwindling water resources at local, regional, and even international level, as opposed to cooperating and openly disseminating information on water systems.

Our proposed direction is to reconcile water supply and demand across countries' regions. One of the ways is through consolidated efforts of all agencies concerned with water, land, and climate to encourage water conservation and effectively manage the financial performance of the sector. A financially sound and effectively managed irrigation sector can generate the funds required for infrastructural development and investment in irrigation efficiency, which is crucial, since many high-performing irrigation technologies – such as micro-irrigation and precision farming – are quite costly to implement. Another approach is to gradually transition away from cultivating water-intensive crops, especially in water-stressed regions. Furthermore, while both countries are already taking steps towards Integrated Water Resource Management, strengthening these efforts further could lead to the establishment of financially stable and transparent water governance systems that involve stakeholders at all levels. In any case, safeguarding the incomes and livelihoods of agricultural workers from the impacts of both gradual and sudden climate-related hazards remains a primary concern.

The strategies proposed in this context may also be applicable to other countries in the Global South that are at various stages of irrigation development. However, as evident from the cases of India and Tajikistan, the local context is crucial, and policies need to be carefully customized to the unique characteristics of each country.

Acknowledgements

The authors would like to thank Nidhi Nagabhatla for her excellent comments and suggestions on an earlier version of this working paper.

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UNU-CRIS Working Paper #03 2024

Published by: United Nations University Institute on Comparative Regional Integration Studies

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